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ATOLL RESEARCH BULLETIN

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by Richard G. Buggeln

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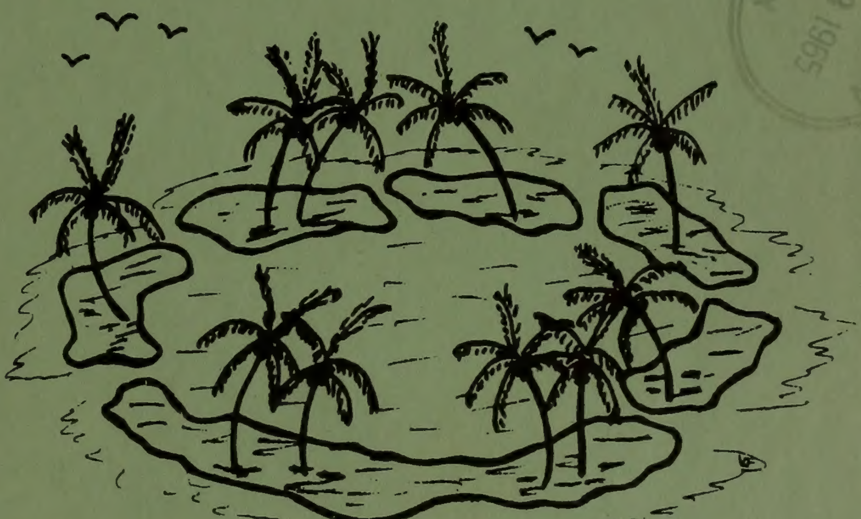

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past eighteen years.

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A preliminary list of the algal flora of the Midway Islands

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A preliminary list of the algal flora of the Midway Islands

by

Richard G. Buggeln[1]

Algal collections which have been reported from the Hawaiian Islands are largely based on materials collected from the more accessible and most heavily populated islands of Oahu, Maui, Molokai, Hawaii, and Kauai. However, collections have also been recorded from two of the lesser islands in the northwestern part of the Hawaiian chain: Laysan Island (Lemmermann, 1905) and Pearl and Hermes Reef (Howe, 1934). To the author's knowledge there have been no published reports of algae collected from the Midway Islands--two islands situated on one of the last atolls toward the northwestern end of the Hawaiian archipelago.

On a trip to the Midway Islands, January 12 through 16, 1962, Dr. Charles H. Lamoureux of the Botany Department, University of Hawaii, collected algae which had drifted onto several of the beaches of both islands after a storm. These algae are listed below.

The Midway Islands (177°25' W. Longitude and 28° 15' N. Latitude) are on an atoll located 1300 statute miles northwest of Honolulu, Hawaii. The diameter of this circular coral atoll is about 5 miles. Wide reefs jut out of the water on the northeast side. The two islands, Sand and Eastern, are situated in the lagoon inside but near the southern rim. Around the inside of the rim of the atoll is a wide margin of shallow water which drops off toward the center of the atoll into the depths of the lagoon.

Sand Island, the larger of the two islands, is one and a half miles in length along the north-south axis and a mile wide along the east-west axis. The island has a maximum elevation of 43 feet. Eastern Island, located about a mile and a half across the shallows to the east of Sand Island is relatively flat and triangular in shape. The longest of the three sides of the island is oriented in an east-west direction and is about one and a half miles long.

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[1] Botany Department, University of Hawaii, Honolulu, Hawaii 96822.

The collection numbers cited are those of the catalogued serial listings of the specimens in the herbarium of Dr. Maxwell S. Doty, Botany Department, University of Hawaii. The material from Sand Island has the following numbers: 18725 to 18731, and 18739 to 18754; those specimens from Eastern Island have the numbers: 18704 to 18719, 18732 to 18738, and 18754 to 18762.

Acknowledgments

The author wishes to thank both Dr. Maxwell S. Doty and Dr. Albert J. Bernatowicz for their critical reading of this manuscript and for allowing the author to use their libraries during the preparation of this floral list.

CYANOPHYTA

Lyngbya majuscula Gomont, 1892: 151, pl. 3, figs. 3 & 4.

Collection numbers 18756, 18715, 18742B, and 18754F.

Masses of long intertwining filaments, 65 microns in diameter were frequently entangled with larger algae.

CHLOROPHYTA

Ulva sp.

Collection number 18719.

The specimens, too young for specific identification, were ovoid in shape, 1 to 2 cm in breadth.

Boodlea vanbosseae Reinbold *in* Weber van Bosse, 1913: 70, 12; Dawson, 1956: 29, fig. 6.

Collection number 18761.

This was a thickly woven mass of filaments composed of cells 150 to 175 microns wide and 2 to 4 times as long. A main axis or axes could not be distinguished by the size of the filaments: They all had a uniform diameter. Frequently, the apical cell of the filament had developed into a long multicellular rhizoid of slender diameter and anastomosed with another filament through the production of a tenacular cell. The material agrees with that figured in Weber van Bosse (1913).

Boodlea sp.

Collection number 18755.

The material was matted more or less loosely and entangled with and connected with pieces of coral and *Halimeda*. Branching occurred at random with laterals cut off by a crosswall but not necessarily near the transverse wall of the parent cell. Frequently a lateral of indeterminate length was long and attenuated and had produced a terminal tenacular cell which adhered to another filament. The diameter of the major axis near the basal holdfast was 200 microns and that of the secondary axes above was 150 microns.

Microdictyon setchellianum Howe, 1934; Egerod, 1952: 366, pl. 33, fig. 6c-g.

Collection number 18719B.

This loose to compact clump, 1 cm across, was growing intertwined with *Jania capillacea* (18719J). The diameter of the cells was 450 microns with no prominent central axis.

Struvea anastomosans (Harvey) Picc. & Grun. ex Piccone, 1884a; Egerod, 1952: 359, pl. 31, fig. 4a-h.

Collection number 18709.

This specimen was growing on a small basalt stone.

Udotea javensis (Montagne) A. & E. S. Gepp, 1904; Taylor, 1950: 73.

Collection number 18706B.

This small specimen was 3.5 mm high from rhizoid to apex with a stipe of 110 microns and with filaments of 55 microns diameter composing the monostromatic blade. The blade had a width of 1 mm; the individual filaments of the blade were constricted at irregular intervals above the dichotomies. The specimen was referred to this species because *U. javensis* has been commonly reported from Hawaiian waters. It is possible, however, that the alga might be a juvenile stage of a larger species of *Udotea*.

Codium arabicum Kuetzing, 1856; Egerod, 1952: 382, pl. 34, b. figs. 11-13.

Collection numbers 18741A and 18712B.

The thalli, 4 cm across, were flattened and closely appressed to the surface of coral fragments.

Codium edule Silva in Egerod, 1952: 392, pl. 35, b, fig. 18.

Collection numbers 18740B, 18759B, 18741B, 18712B, 18725C, and 18733.

The specimens all displayed the characteristic anastomosing between the dichotomous branches. The longest of the specimens was 10 cm. The branches were frequently anastomosed with the segments of Halimeda incrassata.

Codium reediae Silva in Egerod, 1952: 389, pl. 36, fig. 17.

Collection numbers 18740A, 18733A, 18725A, 18712A, and 18759A.

The collection included specimens of 15, 20, and 25 cm in length. The branching was freely dichotomous with no anastomosing between branches.

Halimeda discoidea Decaisne, 1842; Hillis, 1959: 352, pl. 2, fig. 5; pl. 5, fig. 11; pl. 6, fig. 11.

Collection number 18705.

A single sterile specimen about 8 cm high was identified. The size of the segments was quite variable in both width and length and they were lightly calcified with an average thickness of 1 to 1.4 mm. The largest segment was 2 x 1.25 cm. Two to 5 segments arose from the spical end of each lower segment. In surface view, the utricles were 5 to 7 sides and asymmetrically compact with no interutricular spaces. The outer surfaces appeared smooth with a diameter of 70 to 100 microns.

Halimeda incrassata (Ellis) Lamouroux, 1816; Hillis, 1959: 365, pl. 4, fig. 1-2; pl. 5, fig. 6, fig. 21-24.

Collection numbers 18707, 18747, 18738, and 18758.

The collections included fragments of larger thalli and one entire alga 6 cm in height. The segments were heavily calcified and of uniform size and shape, 4 to 7 mm in width and 4 mm high. In surface view, the utricles were round to slightly oval and measured 10 to 18 microns in diameter. The utricles were not appressed to each other and interutricular spaces were present. The branching was di- and trichotomous and in one plane.

PHAEOPHYTA

Ectocarpus indicus Sonder in Zollinger, 1854; Børgesen, 1941: 16, figs. 6-7.

Collection number 18762.

The fragmentary material was sterile but the method of branching was indicative of the species. The laterals arose from a central uniseriate filament with an acute adaxial angle between the lateral and central axis. The cells in the filaments were quite variable in length.

Sphacelaria sp.

Collection numbers 18746, 18754D, and 18703D.

All of the material, 8 mm high, was too young for certain specific identification. The propagules were knob-like and measured 100 microns long by 70 microns wide at the expanded apex, but it appeared that the divisions at the widened portion were not yet completed. At this stage of growth, the propagules could develop into either those of S. tribuloides or S. novae-hollandiae. Unilocular sporangia with a diameter of 40 microns were borne on short pedicels. The segments of cells composing the vegetative axes had a length and breadth of more or less equal dimensions.

Dictyota crenulata J. Agardh, 1847; Børgesen, 1914: 56, figs. 36-37.

Collection number 18734.

The fragmentary material had the distinct small crenulations along the margins which suggested that the 2 cm pieces could be placed in this taxon.

Dictyota divaricata Lamouroux, 1809; Taylor, 1928: 120.

Collection number 18754.

This single specimen measured 6 cm in length, 3 mm broad at the torn-off base, and 10 microns wide at the attenuated tips. The material was fertile and bore mature spherical oogonia 6 to 8 microns in diameter. These were not grouped into sori, although frequently in triads, but were generally evenly distributed toward the tip of the thallus. The reproductory structures were considered to be oogonial rather than sporangial because of the absence of the classical 'tetrasporic' divisions which are characteristic of the sporangia in this genus.

Zonaria sp.

Collection numbers 18729, 18745, and 18716.

The material was young. In cross-section the medulla consisted of one layer of large square cells. The cortex, both above and below, was also mostly monostromatic with evidence of ensuing periclinal divisions. On the ventral surface rhizoids were present.

RHODOPHYTA

Falkenbergia hillebrandii (Bornet) Falkenberg, 1901; Bøergesen, 1910: 199, fig. 17; Feldmann & Feldmann, 1942: 89.

Collection number 18751.

This sterile material was epiphytic on segments of *Halimeda incrassata.* Fragments of this species were also commonly found with other small epiphytes.

Asparagopsis taxiformis (Delile) Coll. & Herv., 1917; Bøergesen, 1915-1920: 352, figs. 347-351.

Collection numbers 18742 and 18714.

The specimens were 7 to 8 cm high with rhizoidal, creeping bases attached to segments of *Halimeda incrassata*. Club-shaped spermatangial stichidia, 700 microns long,were borne on lateral branchlets. These had a basal diameter of 74 microns and 225 microns at the apex.

Galaxaura cylindrica (Ell. & Soll.) Kjellmann, 1900: 64, pl. 8, figs. 34-42.

Collection numbers 18750 and 18736.

Two sterile specimens of 7 and 9 cm height were identified by Mr. Gavino Trono, Jr., Botany Department, University of Hawaii.

Hydrolithon reinboldii (W. v-B. & Foslie) Foslie, 1909; Weber van Bosse & Foslie, 1904: 49, fig. 21, pl. 10, fig. 1-6.

Collection numbers 18748 and 18749.

This coralline crust was growing on coral fragments. The hypothallial cells were 15 microns long and the perithallus was constructed of irregularly shaped cells. The specimens corresponded well with the description and figures in Weber van Bosse & Foslie (1904).

Jania capillacea Harvey, 1853; Dawson, 1953: 116.

Collection numbers 18712, 18719J, and 18735.

The small alga of 3 mm height was found frequently entangled with larger algae including *Microdictyon setchellianum*. The diameter of the dichotomously branching axes was 100 to 110 microns. The material was sterile.

Hypnea spinella (J. Ag.) Kuetzing. 1849; Bøergesen, 1920: 384, fig. 369.

Collection numbers 18710 and 18757.

Several small clumps 2 to 4 cm in diameter and 1 cm high were identified. These clumps of intricately woven, terete axes with short spiny lateral branches frequently anastomosed with each other and with segments of *Halimeda incrassata*. The material was sterile.

Spyridia filamentosa (Wulf.) Harv. in Hooker, 1833; Taylor, 1928: 197, pl. 28, figs. 14-18.

Collection numbers 18760, 18737, 18728, and 18706.

The specimens varied in height from 2 to 8 cm and fragments were commonly extracted from other algae. Tetrahedral tetraspores were cut off by nodal corticating cells of the uniseriate laterals. The tetraspores, occurring 3 to 5 on a branchlet, tended to be borne on the adaxial surface although they were often produced laterally.

Centroceras clavulatum (Ag.) Montagne *in* Durieu, 1846; Taylor, 1950: 139.

Collection number 18763.

This material was epiphytic on segments of *Halimeda incrassata* and also commonly found on other algae.

Dasya pedicellata (C. Agardh) C. Agardh, 1824; Taylor, 1937: 326; Dawson, 1954: 451, fig. 56j.

Collection number 18743.

A single tetrasporic specimen 3.5 cm high, attached to a piece of coral, was identified as *D. pedicellata* by comparison with Dawson's collection (1954) of a short mature specimen of similar description which he placed in this taxon. The main axes were nude below but densely covered with branching monosiphonous laterals above. The lateral filaments had a diameter of 25 to 35 microns at the base and 5 to 7 microns at the tip. The juvenile stichidia were 230 to 250 microns in length, 80 to 90 microns wide, and lanceolate in shape. The tetraspores, the largest with a diameter of 25 to 30 microns, were not yet fully divided. With the exception of the small stature, this specimen agrees with the description given by Taylor (1937).

Taenioma perpusillum J. Agardh, 1863; Okamura, 1930: Icones 6, pl. 264, figs. 17-19.

Collection numbers 18726, 18753, and 18750B.

This alga was commonly mixed with the other small epiphytic algae and was easily recognized by its dorsi-ventral habit, terminal trichoblasts at the ends of the erect axes, and the single-celled rhizoid arising from a ventral pericentral cell with no crosswall separation. The diameter of the prostrate filament was 140 microns and the rhizoids, 45 microns. The material was sterile.

Herposiphonia tenella (C. Ag.) Ambronn, 1880: Bøergesen, 1918: 286, figs. 287-289.

Collection numbers 18730, 18707, and 18754A.

The creeping, prostrate portion of this small epiphyte gave rise to erect branches 1 mm in height at random intervals along the dorsal surface of the prostrate filaments; rhizoids were cut off from the apical end of the ventral pericentral cells of nearly every segment. The diameter of the prostrate portion was 125 microns and the erect, 60 to 85 microns. The alga was a common epiphyte among the collections of larger algae. No fertile material was found.

Polysiphonia sp.

Collection numbers 18713, 18750, and 18704.

These specimens were commonly found on coral fragments, segments of *Halimeda*, and mixed with other small algal epiphytes. Both the branching, prostrate system and the non-branching, erect filaments had 12 to 15 pericentral cells. The erect axes, born dorsally on the prostrate axes, were separated from each other by one or more segments with no apparent regularity. The pericentral cells were 50 microns long and 135 microns in diameter. Unicellular rhizoids were cut off by a crosswall and arose from the *middle* of the ventral pericentral cells of the prostrate axes. The tips of the rhizoids were either slightly branched or discoid. No fertile material was found.

Polysiphonia sp.

Collection number 18704A.

The erect axis, 6 mm high, was composed of segments of 4 pericentral cells; each pericentral cell measured 140 microns square. There were no prostrate portions, and the erect filament arose from a basal clump of rhizoids. Above one pericentral cell in each segment was a scar cell. These latter cells were arranged in a spiraling sequence on the thallus. This specimen agreed with one of Dr. G. J. Hollenberg's tentative species, in manuscript.

Polysiphonia sp.

Collection numbers 18727 and 18704.

An erect axis 7 mm long, with 4 pericentral cells was borne from a tuft of rhizoids at the base. The pericentral cells were 140 microns long and 70 microns wide. Prostrate portions were not apparent. Trichoblasts were present only at the tips of the branches with a scar cell present above one pericentral cell in every segment and ultimately arranged in spiral sequence on the thallus. There was little branching except for several major dichotomies. The material agreed with one of Dr. G. J. Hollenberg's tentative species, in manuscript.

Laurencia obtusa (Huds.) Lamouroux var. *densa* Yamada, 1931: 226, pl. 17, fig. c; Dawson, 1954: 458, fig. 61 H.

Collection numbers 18708 and 18732.

Densely entangled mats, 3 to 4 cm high were identified. All axes were approximately 1 mm in diameter and they were frequently anastomosed with *Halimeda*. The primary branches as well as the secondary laterals were given off in spiral succession, the latter were slightly tapered at the base and were up to 5 mm long. The cortical cells were approximately 30 to 40 microns wide and 50 to 60 microns long. The outer periclinal wall of the cortical cells was about 10 microns thick. Lenticular thickenings were common in the medullary cells. The material was sterile.

Laurencia parvipapillata Tseng. 1943b; Dawson, 1854: 458, fig. 61g.

Collection number 18754L.

This small alga, 1.75 cm long corresponded well with Dawson's figure (1954).

Chondria repens Børgesen, 1924; Tanaka, 1963: 66, fig. 4a-d.

Collection numbers 18754C and 18749A.

This material was common on small pieces of coral and was frequently anastomosed with fragments of *Spyridia* and *Laurencia*. This small alga had both a prostrate portion and an erect system, the latter having a height of 4 to 5 mm. The terete vegetative thallus had a nearly uniform diameter of 210 to 250 microns. Tetrahedral tetraspores 70 to 130 microns in diameter were scattered at the ends of erect, determinate branches. The tetrasporangial branches were broadly clavate when young and became less expanded when older. These mature branches had a diameter of 720 to 740 microns at the apex and 250 microns at the axil. Erect vegetative branches produced secondary laterals sparingly. In cross-section, the cortical cells were more or less the same size as the medullary cells, about 100 microns in diameter. The specimens agreed well with Tanaka's description (1963).

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Marine algae from Laysan Island with additional notes on the vascular flora

by

Roy T. Tsuda

Issued by
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Marine algae from Laysan Island with additional notes on the vascular flora [1]

by

Roy T. Tsuda [2]

The Leeward Hawaiian Islands are composed of a chain of nine islands and reefs that extend northwest from Kauai. All of these islands are uninhabited with the exception of Midway, Kure, and French Frigate Shoal. For further details on the separate islands and reefs, see Bryan (1942).

Laysan Island, one of the Leeward Hawaiian Islands, is located about 790 nautical miles northwest of Honolulu at 25° 42' 14" North Latitude, 171° 44' 6" West Longitude. This low coral island is about one and three quarters miles in length and one mile wide with a large salt-water lake occupying the center of the island. The water in this lake is about twice as saline as "normal strength" sea water. The west, north, and south rims of the island reach heights of thirty to forty feet before sloping downward toward the central lake, but the south rim is only about ten feet above sea level. At present this island is a wildlife refuge under the jurisdiction of the Bureau of Sport Fisheries and Wildlife, United States Fish and Wildlife Service, Department of Interior.

Lamoureux (1963), from which all of the above description of the island is taken, gives a short résumé of the topography and history pertinent to the vegetation of this island. He presents an up to date listing of all the species of vascular plants, with their dates of collection or observation, that are recorded from Laysan, including those from his own collections. While he gives the current status of the vascular plants from Laysan, there are no recent papers on the non-vascular plants. Bryophytes have never been reported from Laysan. This is partly due to the unsuitable sandy substratum that covers the major portion of the island. The fungi are another group that has never been reported on, probably because no qualified person familiar with this group has ever visited the island. The author feels that many fungi occur in the soils and in the fecal matter of the thousands of birds that inhabit this island, also that marine fungi may be found near shore.

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Past published listings of the algae from Laysan are based solely on Schauinsland's collections during 1896-1897 which were identified and published in both Reinbold (1899) and Lemmermann (1905). Schauinsland spent three months on the island and made extensive collections of the algae, particularly concentrating on the phytoplankton. He listed (1899) twenty-three species of marine benthic algae which had been determined by Reinbold (1899). Later, Lemmermann published a very comprehensive paper (1905) on the algal flora of the Hawaiian Islands. His paper lists forty-five species of marine algae based on Schauinsland's collections from Laysan including nineteen of the twenty-three species listed by Schauinsland in his 1899 paper. Also included by Lemmermann are fifty-one species of marine phytoplankton collected by Schauinsland between Laysan and Oahu. The specimens collected by Schauinsland were not seen by the author. In 1918 MacCaughey published a treatment of all the known algae from the Hawaiian Islands which is partly based on Lemmermann's list.

In the spring of 1923, the Tanager Expedition visited Laysan for one month. Mr. Edward L. Caum, one of the botanists on this expedition, reported in his field notes that twenty-six algal collecting stations were made on or near this island--twenty stations along the shore of the island, five from dredging stations in 20-40 meters of water, and one station in the salt-water lake. Mr. Caum's original field notes are in the possession of the Bishop Museum, Honolulu, Hawaii. There is no species list of the algae found from these stations in those notes nor in any of the other published works concerning this expedition. Forty-three species or varieties of algae from Laysan collected by the Tanager Expedition were found in the Herbarium at the B. P. Bishop Museum. They are included in the present paper. The specimens of vascular plants collected from Laysan during the Tanager Expedition and some of the specimens of Schauinsland's may be found in the Herbarium at the Bishop Museum.

In 1961 Dr. Charles H. Lamoureux collected a few marine algae which were not reported in his 1963 paper. To the author's knowledge, no other algal collections were made on this island between the time of Dr. Lamoureux's visit and the author's visit.

Past records of algal collections are also available from two other islands in the Hawaiian Leeward Group. Howe (1934) lists fifteen species of marine algae collected by Dr. Paul C. Galtsoff from Pearl and Hermes Reef. The other record is Buggeln's recent paper (1965) listing thirty-four species of marine algae collected by Dr. Lamoureux from Midway Island.

Through the courtesy of both the Hawaii State Fish and Game Division under the Department of Land and Natural Resources and the United States Coast Guard, the author was able to visit Laysan Island in December 3-10, 1963, making extensive collections of both the vascular plants and the marine benthic algae. Water samples for salinity analyses were also obtained from the salt-water lake and along the seashore.

The main objective of this paper is to provide an up to date listing of all the marine algae collected from Laysan Island, which consists of collections by Schauinsland (1896-1897), Tanager Expedition (1923), Lamoureux (1961) and the author (1963). The encrusting coralline algae collected by the Tanager Expedition are excluded; otherwise this list, together with Lemmermann's paper (1905), provides a complete listing of all the algae both benthic and planktonic thus far recorded from Laysan. Also included in this paper is a list of the twenty-two vascular plants collected by the author in December, 1963, with some miscellaneous notes pertinent to the terrestrial flora. A brief discussion and records of the salinity data obtained are also included in this paper.

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MARINE ALGAE

In making the algal collections and observations, the author walked along the shore around the island looking for different types of algal habitats and made extensive collections from each area. Seven water samples were taken in reference to algal collection areas along the shore. The collection from each habitat was placed in a separate plastic bag and preserved with 10% formalin in sea water.

The first step undertaken in identifying these algae was to sort those from each collection into the respective genera, giving each entity from each collection a number. The collections made by Dr. Lamoureux are permanently recorded in Dr. Maxwell S. Doty's notebook number 62 with the numbers ranging from 19577-19593; while the author's collections are permanently recorded in his own notebook with collection numbers ranging from 509-609. All of the author's and Dr. Lamoureux's specimens, except those specimens which were sent abroad to be identified, are deposited in Dr. Doty's herbarium in the Botany Department at the University of Hawaii.

Other references, aside from those cited in the bibliography, which proved of immense value in the determination of the species within the Chlorophyta and Phaeophyta were Dr. William J. Gilbert's unpublished field manual of Hawaiian Chlorophyta and the unpublished manuscript on the Hawaiian Phaeophyta by Dr. Maxwell S. Doty and Mr. "W" Jan Newhouse.

The following is a list of the major habitats from which the collections of algae were made. See Fig. 1 for the locations of each of the recent algal collecting stations. The numbers preceding the description of each habitat are the station numbers which are listed consecutively to simplify citation of the habitats in the species list. Other habitats where only one species was found are not designated by a station number since habitat can be fully described under the appropriate species.

Collections made by Schauinsland, 1896-1897

STATION 1 - Laysan Island (Schauinsland (1899) and Lemmermann (1905) did not elaborate on the particular area of the island from which the algae were collected).

Collections made by the Tanager Expedition, April, 1923

STATION 2 - Laysan Island (few habitat descriptions were available on herbarium labels).

Collections made by Lamoureux, September, 1961

STATION 3 - On coral ridge on south and southwest sides of island (19579-19584).

STATION 4 - Beachdrift on the north shore of island (19585-19593).

Collections made by Tsuda, December, 1963

STATION 5 - On reef, about one meter deep, near shoreline on northwest side of island about two hundred meters south of main boat entrance. Reef flat largely barren and very brown in color. Fig. 3 shows this reef flat during high tide (509-519).

STATION 6 - On two large coral heads which appeared completely green in color from algal growth of Ulva and Enteromorpha. These coral heads were exposed during low tide (520-521).

STATION 7 - On slightly wave-washed coral ledge on west side of island. Salinity recorded as 35.01 °/oo (522-533).

STATION 8 - In a long shallow tidepool, about half a meter deep, which runs parallel to the shore at the northernmost point on the large coral ridge (about 250 meters long) on southwest side of island. At low tide, this tidepool is easily accessible, whereas at high tide it is almost impossible to reach without being washed over the seaward ledge. Fig. 2 shows this coral ridge during high tide. Salinity recorded as 35.19 °/oo (534-539).

STATION 9 - In tidepool on southernmost point of this same large coral ridge as in "Station 8" (540-576).

STATION 10 - Beachdrift on northwest shore (577-592).

STATION 11 - On wave-washed coral ledge on northeast side of island. Salinity recorded as 35.17 °/oo (593-606).

The following is an annotated list of all the blue-green, green, brown and red algae that were collected from Laysan Island by the four collectors cited above. The station numbers and those collection numbers present are cited with each binomial, and will serve to indicate the respective algal habitat from which the collection was made and the person or expedition who made the collection, with the dates. Since the determinations of Schauinsland's collections were made many years ago, many of the names of his species are now relegated to synonymy. In such cases the original names which were listed by Schauinsland or Lemmermann are placed in parentheses under the accepted names with annotations concerning the change included. Those species which represent new algal records from Laysan are preceded by an asterisk.

MYXOPHYTA

Any significant information given in Dr. Francis Drouet's letter to the author is incorporated in the listing below. Since Drouet and Daily, in their "Revision of the coccoid Myxophyceae" (1956), did not have the opportunity to see the holotypes of the coccoid forms determined by Lemmermann from Laysan, they designated them as the types until the specimens could be studied. For the present they place them in a genus or species but tentatively. In the listing below, those coccoid and filamentous Myxophyceae which were not discussed by Dr. Drouet in his letter or by Drouet and Daily (1956) are cited as they appeared in Lemmermann's paper (1905).

***Anacystis dimidiata** (Kütz.) Drouet & Daily, 1952: 221.

Local Habitat: Sta. 2 (in salt-water lake).

Anacystis sp.
(*Coelosphaeriopsis halophila* Lemm.)

Local Habitat: Sta. 1 (in salt-water lake).
Drouet & Daily (1956) tentatively list *C. halophila* under the genus *Anacystis*.

Aulosira schauinslandii Lemm., 1905: 622.

Local Habitat: Sta. 1 (epiphytic on *Turbinaria ornata*)

Calothrix confervicola Bornet & Flahault, 1886: 349.

Local Habitat: Sta. 1 (epiphytic on marine algae)

Entophysalis conferta (Kütz.) Drouet & Daily, 1948: 79.
(*Xenococcus laysanensis* Lemm.)

Local Habitat: Sta. 1 (epiphytic on marine algae)
Drouet & Daily (1956) tentatively list *X. laysanensis* under *E. conferta*.

Entophysalis deusta Drouet & Daily, 1948: 79.
(*Chondrocystis schauinslandii* Lemm.)

Local Habitat: Sta. 1 (Laysan): Sta. 2 (in salt-water lake); in lake on southeast side growing with *Lyngbya aestuarii* (19577); Sta. 7 (531).
According to Dr. Drouet, specimen 19577 is a topotype of *Chondrocystis schauinslandii*.

Gomphosphaeria aponina Kütz., 1836: 151, Drouet & Daily, 1956: 98.

Local Habitat: Sta. 1 (intermixed with marine algae).

Lyngbya aestuarii Gomont, 1893: 147.
(Lyngbya semiplena (C. Ag.) J. Ag.)

Local Habitat: Sta. 1 (Laysan): Sta. 2 (in salt-water lake); in salt-water lake on southeast side (19577); Sta. 7 (531); epiphytic on Sesuvium portulacastrum on north side in salt-water lake, salinity 64 °/oo (607); epiphytic on Cyperus laevigatus on southwest side in salt-water lake, salinity 60 °/oo (608).

This particular alga as determined by Dr. Drouet was growing abundantly as an epiphyte in the salt-water lake. According to Dr. Drouet, specimen 531 is an ecophene (ecological growth-form) usually referred to as Lyngbya semiplena.

Lyngbya meneghiniana (Kütz.) Gomont, 1890: 354.

Local Habitat: Sta. 1 (epiphytic on marine algae).

Microchaete vitiensis Asken. in Bornet & Flahault, 1885: 22.

Local Habitat: Sta. 1 (epiphytic on Liagora coarctata).

*Microcoleus chthonoplastes Gomont, 1892: 354.

Local Habitat: Sta. 2 (in salt-water lake).

Oscillatoria bonnemaisonii Gomont, 1893: 235.

Local Habitat: Sta. 1 (epiphytic on marine algae).

Oscillatoria corallinae Gomont, 1890: 356.

Local Habitat: Sta. 1 (washings from marine algae).

Oscillatoria laetevirens Gomont, 1892: 226.

Local Habitat: Sta. 1 (washings from marine algae).

Phormidium laysanense Lemm., 1905: 619.

Local Habitat: Sta. 1 (epiphytic on Turbinaria ornata).

Schizothrix calcicola (Ag.) Gomont, 1892.
(Lyngbya perelegans Lemm., Lyngbya gloiophila Lemm.,
(Lyngbya mucicola Lemm.)

Local Habitat: Sta. 1 (Laysan) -- all three species listed above in parentheses were listed by Lemmermann; Sta. 2 (in salt-water lake); in salt-water lake on southeast side (19577); epiphytic on Sesuvium portulacastrum on north side in salt-water lake, salinity 64 °/oo (607).

According to Dr. Druoet, specimen 19577 is the topotype of Lyngbya gloiophila Lemm = L. mucicola Lemm. and specimen 607 is the topotype of Lyngbya perelegans Lemm.

Spirulina subtilissima Kütz., 1843: 183.

Local Habitat: Sta. 1 (washings from marine algae).

CHLOROPHYTA

*Acetabularia mobii Solms-Laubach, 1895: 30, pl. 4 (fig. 1); Egerod, 1942: 411, fig. 23i.

Local Habitat: Sta. 9 (549); Sta. 10 (586).
Most of the collections from Station 9 are fertile.

*Bornetella sphaerica (Zanard.) Solms-Laubach, 1893: 92, pl. 9 (fig. 8); Egerod, 1952: 407, figs. 22d-g, pl. 42.

Local Habitat: Sta. 2 (Laysan); Sta. 9 (546)

*Bryopsis pennata Lam., 1809a: 134, fig. 1a-b, pl. 3; Egerod, 1952, 370, fig. 7.

Local Habitat: Sta. 5 (510); Sta. 10(579)
Collections from Sta. 5 were dark green in color with filaments about 5 cm in length. This species was growing in great abundance at this station while very few were found at the other two stations.

*Caulerpa ambigua Okam., 1897: 4, pl. 1 (figs. 3-12); Eubank, 1946: 410, figs. a-b, pl. 22.

Local Habitat: Sta. 9 (548).
Only a few specimens of this species were found along the shore.

Caulerpa racemosa var. *laetevirens* (Mont.) Weber van Bosse, 1913: 106.

Local Habitat: Sta. 1 (Laysan).
The variety listed above is in question. Eubank (1946) says, "I have seen no specimen which can definitely be referred to var. *laetevirens*."

**Caulerpa racemosa* var. *peltata* (Lam.) Eubank, 1946: 421, figs. 2r-s.

Local Habitat: Sta. 2 (Laysan); Sta. 7 (523).

**Caulerpa racemosa* var. *turbinata* (J. Ag.) Eubank, 1946: 420, figs. 20p-q.

Local Habitat: Sta. 2 (Laysan); Sta. 9 (541); Sta. 11 (594).
This variety is found in abundance at both habitats. The ramuli appear bright orange in color.

Caulerpa taxifolia (Vahl.) Ag., 1822: 435; Eubank, 1946: 417.
(*Caulerpa pinnata* (L.) Weber van Bosse sensu Reinbold).

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan).
Eubank (1946) believes that what Reinbold called *C. pinnata* probably refers to *C. taxifolia*.

**Caulerpa webbiana* Montagne, 1838: 129, pl. 6; Eubank, 1946: 415, figs. 1d-f and 2d.

Local Habitat: Sta. 9 (540).
Forming thick mats along the seaward wall of the tidepool with these mats being exposed during low tide.

**Chaetomorpha antennina* (Bory) Kützing, 1849: 379, Boergesen, 1940: 38.

Local Habitat: Sta. 8 (537); Sta. 11 (595).
Forming scattered green tufts at both stations.

**Chlorodesmis hildebrandtii* A. & E. S. Gepp, 1911: 16, 137, figs. 74-75; Egerod, 1952; 377, fig. 9b, pl. 34a.

Local Habitat: Sta. 2 (Laysan); Sta. 11 (605B).
A short filament found intermixed with *Ceramium fimbriatum* and *Centroceras clavulatum*.

Dictyosphaeria cavernosa (Forsk.) Børg., 1932: 2, pl. 1 (fig. 1); Egerod, 1952: 350, fig. 1e-g.
(Dictyosphaeria favulosa (Ag.) Dcne.)

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 4 (19585B); Sta. 10 (588A).

The binomial D. favulosa is now a synonym of D. cavernosa. Specimen 19585B was determined by Dr. Gilbert.

*Dictyosphaeria versluysii Weber van Bosse, 1905: 1944; Egerod, 1952: 351, figs. 1a and 2h-k.

Local Habitat: Sta. 2 (Laysan); Sta. 7 (533); Sta. 9 (542); Sta. 10 (588B).

*Dictyosphaeria sp.

Local Habitat: On coral reef in water about half a meter deep on southeast side of island (19578).

This entity is recorded in Dr. Doty's notebook as belonging to this genus with no specific epithet given. It may very well and probably does fall in one of the two species listed above. The specimen itself cannot be found by the author at present.

*Enteromorpha tubulosa Kützing, 1856: 11; Dawson, 1954: 384, fig. 6a-b.

Local Habitat: Sta. 2 (Laysan); Sta. 6 (520); Sta. 9 (544); Sta. 11 (596).

*Enteromorpha sp.

Local Habitat: Sta. 3 (19579).

This specimen is recorded as such in Dr. Doty's notebook but the specimen itself cannot be found.

*Haliméda discoidea Decaisne, 1842: 91; Hillis, 1959: 352, pl. 2 (fig. 5), pl. 5 (fig. 11), pl. 6 (fig. 11), pl. 7 (figs. 9-10), pl. 8 (figs. 5-8), pl. 11.

Local Habitat: Sta. 2 (Laysan); Sta. 4 (19590); Sta. 5 (509); Sta. 10 (577).

This species is present on all reef flats around the island. Specimen 19590 was determined by Dr. Gilbert and the latter two by Dr. Llewellya Hillis Colinvaux.

*_Halimeda lacunalis_ Taylor, 1950: 91, pl. 51; Hillis, 1959: 349, Pl. 1 (fig. 1), pl. 5 (fig. 6), pl. 6 (fig. 13), pl. 7 (fig. 8), pl. 9.

Local Habitat: Sta. 2 (Laysan).

If the author's determination is correct, this species is a new record for the Hawaiian Islands.

Halimeda opuntia (L.) Lam., 1816: 308; Hillis, 1959: 359, pl. 2 (figs. 7-8), pl. 5 (figs. 3-4), pl. 6 (fig. 6), pl. 7(fig. 3), pl. 10.

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 4 (19586).

Specimen 19586 was determined by Dr. Gilbert.

Microdictyon setchellianum Howe, 1934: 38; Egerod, 1952: 366, figs. 6c-g, pl. 33.

(_Microdictyon umbilicatum_ (Velley) Zanard.)

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 4 (19592); Sta. 7 (529); Sta. 9 (543); Sta. 10 (583); Sta. 11 (606).

The name _M. umbilicatum_ is now a synonym of _M. setchellianum_. Specimen 19592 was determined by Dr. Gilbert.

*_Palmogloea protuberans_ (Sm. & Sow.) Kützing, 1843: 176.

Local Habitat: Sta. 2 (dredged from bottom of salt-water lake in 5-7 meters of water).

This species was determined by Mr. Newhouse.

*_Pringsheimiella acutata_ (Reinke) Schmidt & Petrack, 1934: 29; Kenyon & Rice, 1959: 248; Taylor, 1960: 51.

Local Habitat: On the molted fur of the Hawaiian monk seal, _Monachus schauinslandi_ Matschie (19593B).

This green alga collected by Dr. Lamoureux was readily seen by the author growing abundantly on the faces and bellies of the sub-adult seals. It seems that the younger seals spend more time in the water and collect a more abundant algal growth. Fig. 9 shows a photograph of the seal on which this species of alga was growing.

**Ulva fasciata* Delile, 1813: 153; Bøergesen, 1940: 10.

Local Habitat: Sta. 2 (Laysan); Sta. 6 (521); Sta. 9 (545); Sta. 11 (597).

Fronds deeply cleft with the clefts extending most of the way to the holdfast.

Ulva rigida Ag., 1824: 410.

Local Habitat: Sta. 1 (Laysan).

Gilbert (unpublished manuscript) lists this species as occurring in Hawaii.

PHAEOPHYTA

**Chnoospora minima* (Hering) Papenfuss, 1956: 69.

Local Habitat: Sta. 2 (Laysan); Sta. 11 (593).

Dictyota acutiloba J. Ag., 1848: 92.

Local Habitat: Sta. 1 (Laysan).

**Dictyota divaricata* Lam., 1809: 331.

Local Habitat: Sta. 9 (553).

**Dictyota friabilis* Setchell, 1926: 91, pl. 13 (figs. 4-7) and pl. 20 (fig. 1).

Local Habitat: Sta. 4 (19593); Sta. 5 (513); Sta. 7 (525); Sta. 10 (578).

Growing in clumps with fronds prostrate in nature.

**Ectocarpus breviarticulatus* J. Ag., 1847: 7; Setchell, 1924: 171, fig. 37.

Local Habitat: Sta. 9 (555); Sta. 11 (602).

Intertangled tufts with filaments having distinctly hooked branchlets. The slightly oblong plurilocular organs are about 40 µ long and 33 µ wide.

Ectocarpus indicus Sonder _in_ Zollinger, 1854: 3.
(_Ectocarpus simpliciusculus_ var. _vitiensis_ Asken.)

Local Habitat: Sta. 1 (epiphytic on _Turbinaria ornata_).

In their unpublished manuscript on the Hawaiian Phaeophyta, Dr. Doty and Mr. Newhouse believe that the variety collected by Schauinsland is probably a small form of _E. indicus_ Sonder.

Hydroclathrus clathratus (C. Ag.) Howe, 1920: 590; Dawson 1954: 403, fig. 18b.
(_Hydroclathrus cancellatus_ Bory sensu Reinbold).

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 9 (559).

Doty and Newhouse (unpublished manuscript) believe that what Schauinsland collected was probably _H. clathratus_.

*_Padina crassa_ Yamade, 1931: 67 and 69.

Local Habitat: Sta. 2 (Laysan).

*_Padina japonica_ Yamada, 1931: 67 and 69, pl. 19 (fig. 2).

Local Habitat: Sta. 9 (558).

Thalli two cells thick throughout with oogonia distributed in concentric rings on the lower surface of the frond.

*_Pocockiella variegata_ (Lam.) Papenfuss, 1943: 467, figs. 1-14.

Local Habitat: Sta. 3 (19581); Sta. 9 (556).

*_Ralfsia_ sp.

Local Habitat: Sta. 2 (Laysan)

*_Sargassum echinocarpum_ J. Ag., 1848: 327.

Local Habitat: Sta. 2 (Laysan).

This sterile specimen is tentatively placed in this species.

*Sargassum obtusifolia J. Ag., 1848: 339.

Local Habitat: Sta. 3 (19580); Sta. 8 (534, 535); Sta. 9 (552). All of the collections except 534 have long strap-like leaves with the receptacles elongated and appearing warty. Specimen 534 which is sterile has short thick leaves. Proliferations on the primary branches are absent on all the collections. Bladders formed at the apex of short flattened leaves are found on only one of the specimens (535). All collections are about 6 cm high. Although there may be some discrepancy between the description given above and the original description of this species, these specimens will be placed under the above species for the present.

Sargassum polyphyllum J. Ag., 1848: 308.

Local Habitat: Sta. 1 (Laysan).
Lemmermann (1905) also lists S. polyphyllum var. fissifolium Grun. but for the present this variety will be just mentioned here under the specific name.

*Sphacelaria tribuloides Meneghini, 1840: 2; Børgesen, 1941: 41, figs. 18a-c

Local Habitat: Sta. 9 (554).

Turbinaria ornata (Turn.) J. Ag., 1848: 266; Taylor, 1963: 483.

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 9 (551).
Most of the recent collections are made up of juvenile specimens which appear as long intertangled filaments. Only in a few thalli is the peltate apex visible.

Zonaria sp.
(Stypopodium lobatum Kütz.)

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan); Sta. 9 (557); Sta. 10 (584).
The illustration which Kützing, 1859, Tab. Phyc. 9, pl. 63 (fig. 2), shows of S. lobatum looks very much like the undescribed Zonaria which is found in Hawaii.

RHODOPHYTA

Amansia glomerata C. Ag., 1824: 247.

Local Habitat: Sta. 1 (Laysan); Sta. 9 (572).

Amphiroa fragilissima (L.) Lam., 1816: 298; Taylor, 1960: 403, pl. 47 (figs. 1 and 2).

Local Habitat: Sta. 1 (Laysan); Sta. 4 (19591A); Sta. 5 (512); Sta. 10 (589).

*Antithamnion sp.

Local Habitat: Sta. 8 (538 - epiphytic on Chaetomorpha antennina); Sta. 9 (562 - intermixed with Ceramium fimbriatum).

Central axis about 130 u wide with sessile tetrasporangia forming laterally on branches which are about 5 mm long and 20 u wide. Tetrasporangium measured 50 u long and 40 u wide.

*Asparagopsis taxiformis (Delile) Collins & Harvey, 1917: 117.

Local Habitat: Sta. 2 (Laysan); Sta. 3 (19583A); Sta. 9 (563). Thalli were never found attached but floating in tidepools or as beachdrift.

*Centroceras clavulatum (Ag.) Montagne in Durieu, 1846: 140; Dawson, 1954: 446, fig. 54h.

Local Habitat: Sta. 2 (Laysan); Sta. 7 (530 - associated with Ceramium fimbriatum); Sta. 9 (569 - epiphytic on Microdictyon setchellianum); Sta. 10 (585 - associated with Hypnea sp. 2)

*Ceramium fimbriatum Setch. & Gard., 1924: 777, pl. 26 (figs. 43-44); Dawson, 1954: 446, fig. 55a; Dawson, 1962: 56.

*_Champia parvula_ (C. Ag.) Harvey, 1853; Tab. Phyc. 16, p. 14, pl. 37e-f; Dawson, 1954: 443, figs. 52e, 53.

Local Habitat: Sta. 2 (Laysan).

*_Chondria_ sp. 1

Local Habitat: Sta. 5 (519).

Thalli about 1 cm long with a terminal depression present at the apex. Both short and long branches are formed laterally on the main axis.

*_Chondria_ sp. 2

Local Habitat: Sta. 11 (598).
Branches present on only one side of the main axis.

*_Chondrococcus hornemanni_ (Mert.) Schmitz, 1895: 170.

Local Habitat: Sta. 2 (Laysan); Sta. 9 (568); Sta. 11 (601).
Collections from both stations were floating in tidepools.

*_Coelarthrum boergensenii_ Weber van Bosse, 1928: 473, figs. 207-208.

Local Habitat: Sta. 10 (592).

Corallina sandvicensis Lemm. 1899: 299.

Local Habitat: Sta. 1 (Laysan); Sta. 2 (Laysan).

*_Gelidium pusillum_ (Stackhouse) LeJolis, 1864: 139; Dawson, 1954: 420, fig. 31a-c.

Local Habitat: Sta. 2 (Laysan).

*_Gelidium_ sp.

Local Habitat: Sta. 2 (Laysan).

*_Haloplegma_ sp.

Local Habitat: Sta. 3 (19583B).

*_Herposiphonia_ sp.

Local Habitat: Sta. 10 (581).

*_Hypnea cervicornis_ J. Ag., 1852: 451; Dawson, 1954: 435, fig. 46d; Tanaka, 1941: 240, fig. 13.

Local Habitat: Sta. 2 (Laysan); Sta. 11 (599).
Thallus is more similar to Dawson's illustration than to Tanaka's.

*_Hypnea esperi_ Bory, 1829: 157; Dawson, 1954: 436, fig. 46h-j.

Local Habitat: Sta. 2 (Laysan).

*_Hypnea pannosa_ J. Ag., 1847: 14; Tanaka, 1941: 247, fig. 20.

Local Habitat: Sta. 5 (518); Sta. 9 (566); Sta. 11 (600).
All of the collections formed clumps on the substratum.

*_Hypnea_ sp. 1

Local Habitat: Sta. 7 (526).
Fragment about 1-2 mm high with thallus complanate with few lateral branches present.

*_Hypnea_ sp. 2

Local Habitat: Sta. 10 (580).
Fragment about one centimeter high with no predominate main axis. The majority of the sub-branches are about 2-4 mm long.

*_Jania capillacea_ Harvey, 1853: 84; Dawson, 1952: 116; Dawson, 1954: 432, figs. 41a-b.

Local Habitat: Sta. 9 (567); Sta. 10 (590B).
Calcareous thalli forming clumps with the individual thallus ranging from 66-120 µ in width.

*Jania decussato-dichotoma (Yendo) Yendo, 1905: 37; Dawson, 1952: 117, pl. 27 (fig. 3); Dawson, 1954: 430, fig. 40f.

Local Habitat: Sta. 4 (19587).

*Jania mexicana Taylor, 1945: 197.

Local Habitat: Sta. 2 (Laysan).

*Jania micrarthrodia Lam., 1816: 271, pl. 9 (fig. 5a-b); Dawson, 1956: 49, fig. 42.

Local Habitat: Sta. 2 (Laysan).

*Jania natalensis Harvey, 1847: 107; Dawson, 1952: 118, pl. 27 (figs. 1-2).

Local Habitat: Sta. 7 (522).

Thalli about 3 cm high with narrow erect branches. Intergenicula more or less uniform in diameter throughout, with short branches arising from intergenicula.

*Jania ungulata Yendo, 1902: 27, pl. 3 (figs. 7-8) and pl. 7 (fig. 8).

Local Habitat: Sta. 4 (19589); Sta. 10 (591).

Thalli about 3 cm high with flat swellings at tips of terminal branches.

*Laurencia corymbosa J. Ag., 1863: 716; Dawson, 1954: 458, fig. 61f.

Local Habitat: Sta. 9 (573).

Rigid thalli about 2-3 cm high.

Laurencia obtusa (Huds.) Lam., 1813: 130; Taylor, 1960: 626; Yamada, 1931: 222, pl. 16 (figs. a-e) and pl. 17 (figs. a-c).

Local Habitat: Sta. 1 (Laysan); Sta. 4 (19588); Sta. 5 (514);
Sta. 7 (524); Sta. 9 (564); Sta. 10 (582);
Sta. 11 (603).

Forming thick red mats completely covering the high coral ledges that were accessible to spray from waves.

*Laurencia perforata (Bory) Mont., 1840: 155; Yamada, 1931: 193, figs. a-b, pl. 3 (fig. b).
(Laurencia vaga Kütz.)

Local Habitat: Sta. 1 (Laysan).

Yamada (1931), after examining a cotype collected by Vieillard in New Caledonia, says that Kützing's L. vaga is probably L. perforata.

*Laurencia pygmaea Weber van Bosse, 1913a: 122, pl. 12 (fig. 6); Yamada, 1931: 201.

Local Habitat: Sta. 11 (604).

*Laurencia sp. 1

Local Habitat: Sta. 9 (565).

*Laurencia sp. 2

Local Habitat: Sta. 9 (560).

*Laurencia sp. 3

Local Habitat: Sta. 5 (515).

*Laurencia sp. 4

Local Habitat: Sta. 2 (Laysan).

*Laurencia sp. 5

Local Habitat: Sta. 2 (Laysan).

Liagora coarctata Zanard.

Local Habitat: Sta. 1 (Laysan).

*Liagora kahukuana Abbott, 1945: 149, fig. 2.

Local Habitat: Sta. 3 (19584).

A large male thallus about 14 cm long. This specimen falls within Abbott's description of this species.

Liagora valida Harv., 1852: 138, pl. 31A (figs. 1-5).

Local Habitat: Sta. 1 (Laysan).

**Liagora* sp. 1

Local Habitat: Sta. 2 (Laysan).

**Liagora* sp. 2

Local Habitat: Sta. 2 (Laysan).

Lithothamnion sp.

Local Habitat: Sta. 1 (Laysan)

**Peyssonelia* sp.

Local Habitat: Sta. 2 (Laysan)

Polysiphonia polyphysa Kütz. 1863: 20.

Local Habitat: Sta. 1 (Laysan).

Menez (1964) says that he could find no specimens of this species in any of the Hawaiian collection. De Toni (1900) believes that this specimen is probably *P. ferulacea*.

**Polysiphonia sphaerocarpa* Bøerg., 1918: 271, figs. 267-271.

Local Habitat: Sta. 8 (539).

Determination made by Dr. Hollenberg.

**Polysiphonia* sp.

Local Habitat: Forming deep red tufts on the neck of a sea turtle, *Chelone mydas* (609).

Filaments arising from a prostrate axis.

*Porolithon sp.

Local Habitat: Sta. 7 (528); Sta. 10 (587).
White calcareous alga covering portion of reef.

*Pterocladia parva Dawson, 1952: 77, pl. 6 (fig. 2).

Local Habitat: Sta. 5 (517).

Summary of Algal Collections

Below is a table summarizing the number of algal species or varieties listed in this paper in each of the major divisions collected by the four collectors from Laysan Island.

Collectors	Myxophyta	Chlorophyta	Phaeophyta	Rhodophyta	Total
Schauinsland (1896-1897)	15	6	6	10	37
Tanager Exp. (1923)	5	14	7	17	43
Lamoureux (1961)	3	7	3	7	20
Tsuda (1963)	3	15	11	28	57

Of these collections, 72 species or varieties are new published records for Laysan. These new records consist of 2 in the Myxophyta, 18 in the Chlorophyta, 11 in the Phaeophyta and 39 in the Rhodophyta.

VASCULAR PLANTS

The following is an annotated listing of the twenty-two species of vascular plants collected from Laysan by the author during his visit there in December 1963. Lamoureux (1963) elaborated on the various vegetation patterns and associations that may be found on the island. From reading this account, the only significant change noticed was that the water from the salt-water lake had risen considerably probably due to heavy rainfall. This rise in water had caused most of the _Sesuvium_-_Cyperus_-_Heliotropium_ association near the edge of the lake to be covered with water. In this listing are two species, determined by Dr. Lamoureux, which were not found in 1961. They are preceded by an asterisk. All of the other determinations were made by the author and later verified by Dr. Lamoureux. Three sets of these plants were prepared and deposited respectively in the herbarium at the Bishop Museum, herbarium at the University of Hawaii and the Hawaii State Fish and Game Division.

Casuarina equisetifolia L.

One tree (Fig. 5) about 5-7 meters high was present on the west side of the island. The Hawaiian terns (_Anous tenuirostris melanogenys_) were using this tree as a nesting site.

Cocos nucifera L.

Nineteen coconut trees were present on the island. The twelve trees at the northwest side of the lake (Fig. 10) seemed in fine condition with the water from the lake not reaching the base of the trees. However, the seven trees on the southeast edge of the lake (Figs. 11-12) had about 15 to 30 cm of water around their bases. The older leaves on most of these southeastern trees were wilting.

*_Conyza bonariensis_ (L.) Cronq.

This plant was growing just south of the campsite (northwest side of island). This was the only area in which these plants were found. All specimens of this weed which could be found were uprooted by Mr. Ronald Walker.

Cynodon dactylon (L.) Pers.

Appearing as a thick green carpet on the northeastern side near the edge of the lake. The Laysan albatross (*Diomedea immutabilis*) were using this area as a nesting site. During the day many Laysan teal (*Anas wyvilliana laysanensis*) were seen by the author in this area.

Cyperus laevigatus L.

This sedge was growing abundantly on the outer edge of the lake, as well as in the lake itself (Fig. 13). Numerous albatross eggs were found abandoned on those sedges which had been flooded by the lake.

Cyperus pennatiformis var. *bryanii* Kükenthal

This variety is endemic to Laysan Island. It was only seen in a restricted area near the southern edge of the lake (Fig. 7).

Eragrostis variabilis (Gaud.) Steud.

Growing in bunches (Fig. 6) throughout the island, making up the major vegetation.

Fimbristylis cymosa R. Br.

Scattered bunches occurring throughout the island.

Heliotropium curassavicum L.

Only one specimen was found on the southwest side of the island in association with *Eragrostis variabilis* and *Ipomoea pes-caprae*. No sign of this species was found near the lake's edge, where Lamoureux (1963) had described it as occurring in abundance. This was probably due to the rise of the water in the lake which apparently covered over the area where this species flourished.

Ipomoea indica (Burm.) Merr.

Occurring in small patch on southwest side of island, halfway between the lake and the beach. This species could not be found elsewhere even though an extensive search was made for it. None of the specimens found were flowering.

Ipomoea pes-caprae (L.) Sw.

This low creeping vine was found in abundance near the lake. Numerous lavender flowers were present.

Messerschmidea argentea (L. f.) Johnston

Only one tree (Fig. 4), about 2 meters high, was present on the beach near the *Scaevola* bushes about fifty meters north of main boat entrance. At a distance this tree appeared dead because only the bare trunk and branches were seen. On closer observation, new shoots were seen arising from the base of this trunk and in the axils of the branches.

Nama sandwicensis var. *laysanicum* Brand

Appearing as flat patches on the beach mostly concentrated on the northwest side of the island.

Nicotiana tabacum L.

Growing about 1-1.5 meters high, found most abundantly on the western side of island (Fig. 8).

Pluchea indica (L.) Less.

Forming entangled bushes predominantly on the northern side of the island near the lake's edge.

Portulacea oleracea L.

Found on the southwestern side of island near the beach. None of these plants were flowering.

Scaevola taccada (Gaertn.) Roxb.

Abundant near the beach around the island. In many instances the Hawaiian monk seal (Fig. 9) could be seen sleeping among the bushes.

Sesuvium portulacastrum L.

Most plants of this species were under water at the lake's edge but, although submerged, they appeared to be living. This species is easily recognized by its bright red stem and small lavender flowers.

Sicyos microcarpus Mann

Flowering specimens of this species were only found on the south side of the island about a hundred meters from the edge of the lake. It is quite possible that the other two species collected by Dr. Lamoureux in 1961 were also present, because this genus was also abundant on the northern side of the island where Dr. Lamoureux had found all three species. Since no flowers or fruits were found on these northern plants, an accurate species determination could not be made. [Lamoureux' record of *S. microcarpus* was accidentally omitted from ARB 97 p. 6. Ed.]

**Solanum nigrum* L.

Only two individual plants were found on the trail leading from the beach to the campsite. Dr. John W. Beardsley, Jr., collected a specimen of this plant on Laysan in 1962.

Tribulus cistoides L.

Growing as a low creeping plant (Fig. 8) abundant throughout the island. This species was easily recognized by its thorny green fruits and pinnately compound leaves.

Seeds

The following is a list of the five species of seeds collected on the beach from Laysan with the number of each in parentheses. They were determined by Miss Marie Neal.

Caesalpinia crista L.	(1)
Cocos nucifera L.	(numerous)
Dioclea violacea Mart.	(1)
Mucuna gigantea DC	(5)
Mucuna urens DC	(1)

Seed Planting

Six species of seeds were planted by Mr. Ronald Walker of the Hawaii State Fish and Game Division near the northwestern edge of the lake during our visit there in 1963. Plantings were made at intervals of ten paces due north from the northernmost coconut tree in the following order.

1. Lepidium o-waihiense C. & S.
2. Cenchrus agrimonioides var. laysanensis F. Br.
3. Achyranthes splendens var. reflexa Hillebr.
4. Chenopodium oahuense (Meyen) Aellen
5. Solanum nelsonii Dunal
6. Lipochaeta integrifolia (Nutt.) Gray

All of the above species or varieties of seeds were collected from Kure, September 1961, with the exception of Chenopodium oahuense which was collected from Nihoa, December 1961. Another planting was made forty-five paces due west of photostation C-3 (marker used by the personnel of the Hawaii State Fish and Game Division for survey purposes) which is located on the northwestern side of the island near the lake's edge. Here the seeds were planted at random.

The seeds of Chenopodium, Solanum, and Sicyos microcarpus planted by Mr. R. Kramer in June 1962 apparently failed to germinate as no specimens could be found at the area of the plantings.

SALINITY DATA

Seven salinity stations were made along the shore of the beach while fifteen salinity stations were made in the salt-water lake. White foam (Figs. 11-12) resembling fine soap suds could be seen accumulated all along the southeastern and eastern edge of the lake. At times this foam was over 30 cm deep and was found to be tasteless. According to Dr. Philip Helfrich, Hawaii Marine Laboratory, similar foam also occurs on the edge of the salt-water lagoon on Christmas Island, one of the islands in the Line Group. Riley (1963) describes a mechanism by which such material is formed, at least in part, by adsorption of dissolved or colloidal material on bubbles and other available surfaces. Once formed the aggregates tend to increase in size, either by agglutination or by further adsorption. The wind blowing from the northwestern side of the island caused this foam to accumulate on the opposite shore.

Two of the fifteen samples from the lake were taken within that area designed as "spring" as shown on the map made by the Tanager Expedition, April 1923. This "spring" is supposedly located on the northeastern edge of the lake, which is at present continuous with the main lake because of the rise in water except for the long row of *Pluchea* bushes partially separating the "spring" from the main lake. The water from the "spring" was found to be less saline than the water from the main lake, probably because of mixing with the fresh water lens in this particular area. It will be noticed that the lake water is much more saline than the surrounding sea water, and that even the "spring" is saltier than the sea.

The salinity data obtained by the author are listed below. All samples were taken from the surface in about one meter of water. See Fig. 1 for the location of each of the salinity stations (encircled numbers).

I. Water from Ocean (surface samples)

1. Slightly wave-washed bench----------------- 35.01 °/oo
2. Tidepool on coral ledge-------------------- 35.19 °/oo
3. Sandy area between shoreline and reef------ 35.14 °/oo
4. Calm shore over reef----------------------- 35.20 °/oo
5. Wave-washed shore-------------------------- 35.17 °/oo
6. Slightly wave-washed bench----------------- 35.12 °/oo
7. Shore off NW boat entrance----------------- 35.15 °/oo

II. Water from Lake (surface samples)

8. Over *Cyperus laevigatus* ------------------ lost
9. Over *Cyperus laevigatus*------------------- 62.00 °/oo
10. Over *Cyperus laevigatus*------------------ 60.00 °/oo
11. Over *Lyngbya aestuarii* and *Cyperus laevigatus*-- 62.00 °/oo
12. Near *Cocos nucifera* --------------------- 61.00 °/oo

13. Over *Cyperus laevigatus*------------------ 60.00 °/oo

14. In puddle, one foot deep----------------- 12.00 °/oo

15. Over *Sesuvium portulacastrum*------------- 60.00 °/oo

16. Over *Sesuvium portulacastrum*------------- 62.00 °/oo

17. Over *Cyperus laevigatus*------------------ 64.00 °/oo

18. Over mud flat---------------------------- 59.00 °/oo

19. Over mud flat --------------------------- 80.00 °/oo

20. Over mud flat---------------------------- 66.00 °/oo

III. "Spring" on NE side of Lake (surface samples)

21. Flooded "Spring"------------------------ 43.00 °/oo

22. Flooded "Spring"------------------------ 53.00 °/oo

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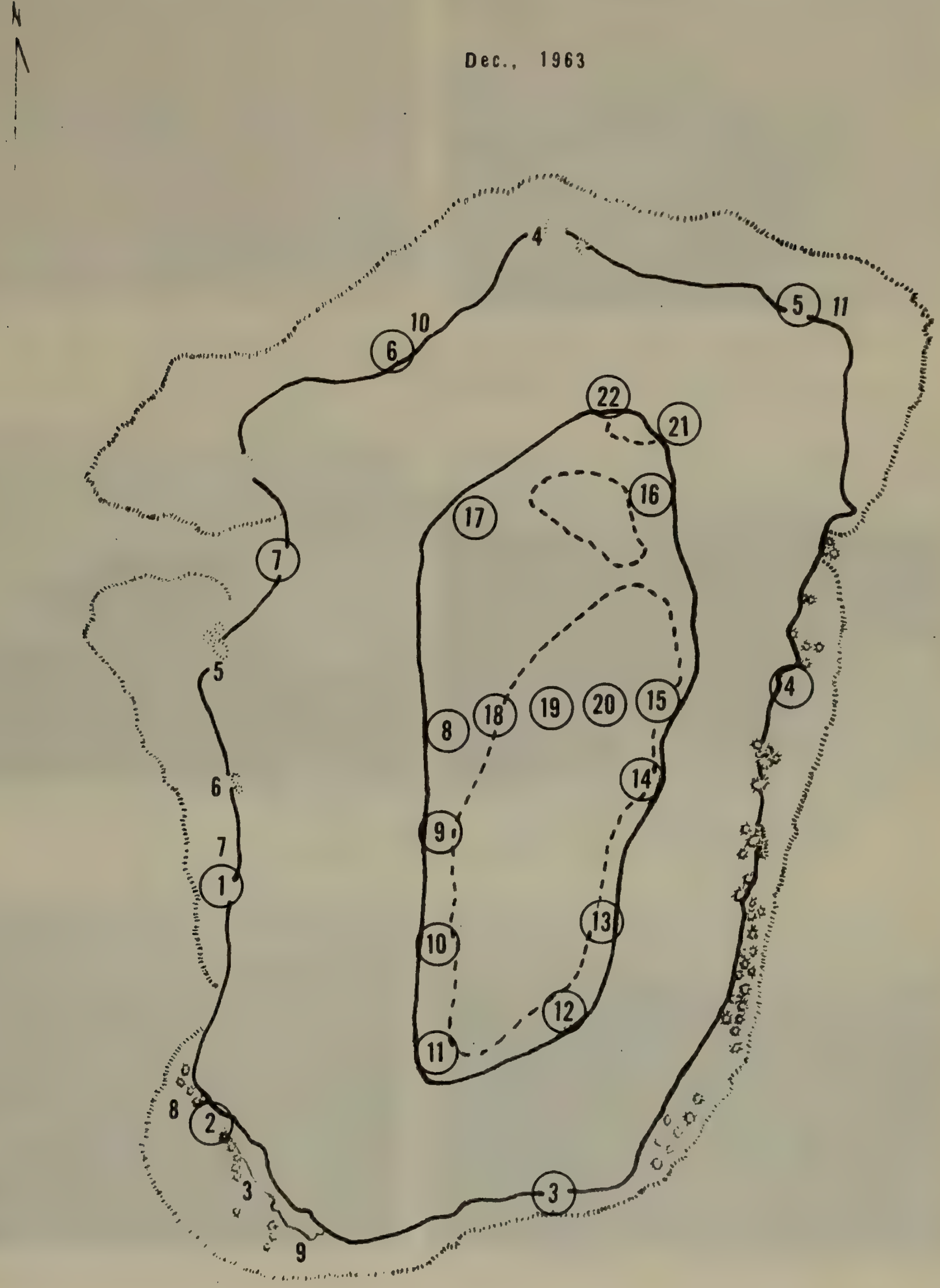
Fig. 1 Map of Laysan Island showing the location of the nine recent algal collecting stations and the twenty-two salinity stations (encircled numbers) taken during the author's 1963 visit to the island. The solid line within the island represents the 1963 water level of the salt-water lake while the inner dotted line represents the 1961 water level. The "spring" can be seen on the northeast corner of the lake.

LAYSAN ISLAND

Dec., 1963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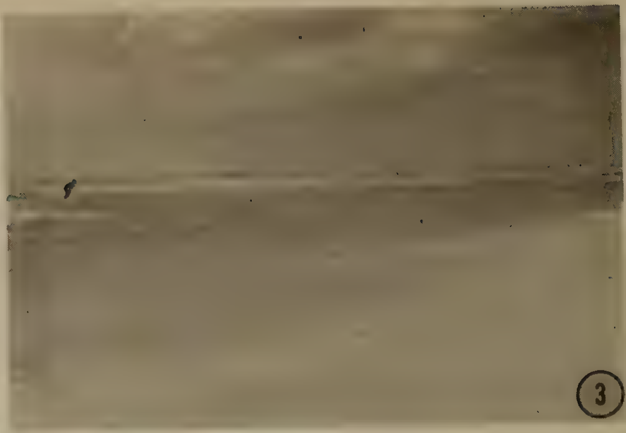
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All photographs were taken on Laysan Island in December 1963.

Fig. 2. View of the large coral ridge on the southwest side of island, during high tide, from which most of the algal collections were made (Stas. 7 and 8).

Fig. 3. View of a sandy area along the west shore facing north. This photograph was taken between algal collection stations 5 and 6. In this area very few algal specimens could be found.

Fig. 4. The only specimen of *Messerchmidea argentea* on the island with *Scaevola taccada* in the background. Notice the new leaves appearing at the base of the trunk.

Fig. 5. The only specimen of *Casuarina equisetifolia* on the island with *Eragrostis variabilis* and *Scaevola taccada* in foreground.

Fig. 6. View from the west side of the island facing the coconut trees on the southeastern side of the island, showing the great abundance of the bunch grass, *Eragrostis variabilis*.

Fig. 7 A small patch of *Cyperus pennatiformis*, a species endemic to Laysan, on the southern side of island. The coconut trees can be seen in the background.

Fig. 8 A few specimens of *Nicotiana tabacum* with *Tribulus cistoides* creeping close to the ground on western side of island.

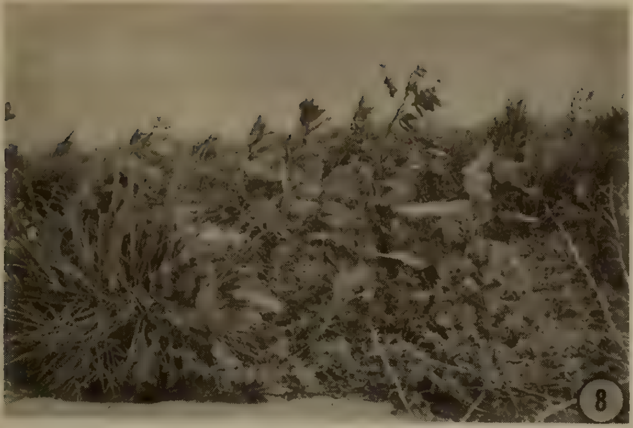
Fig. 9 A Hawaiian monk seal, *Monachus schauinslandi*, and a Laysan albatross, *Diomedea immutabilis*, in *Scaevola* bush.

Fig. 10 The twelve coconut trees on the northwest side of the lake.

Fig. 11 The seven coconut trees on the southeast edge of the lake flooded by water from the lake. The white layer on the surface of the lake was the tasteless foam mentioned in the discussion under the salinity data.

Fig. 12 A closer view of the coconut trees on the southeastern edge of the lake, showing the foam and the water from the lake flooding the bases of the trees.

Fig. 13 View of the northeastern side of the lake facing south, showing the flooded area. Notice how the albatrosses have built up their nests trying in vain to save their eggs. Numerous abandoned eggs were found on the bottom of the lake in about six to twelve inches of water.



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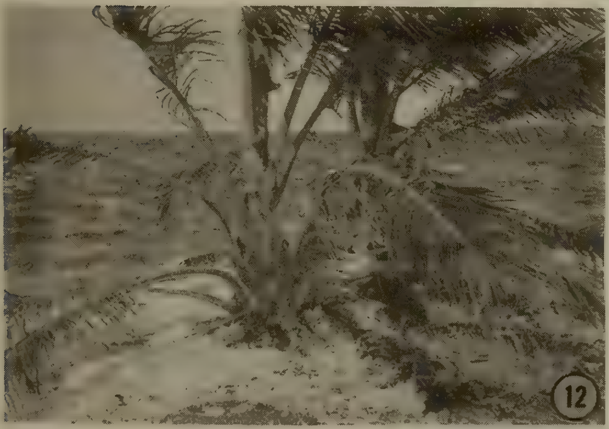

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ATOLL RESEARCH BULLETIN

No. 111

An annotated bibliography of recent papers on corals and coral reefs

by

John D. Milliman

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July 15, 1965

AN ANNOTATED BIBLIOGRAPHY OF RECENT PAPERS ON CORALS AND CORAL REEFS*

by

John D. Milliman**

INTRODUCTION

The articles and books concerned with corals and coral reefs number well into the thousands. In order to bring these works to the attention of the scientific community, many bibliographies have been attempted. The most recent and most complete was compiled by Gilbert Ranson (1958. Coraux et récifs coralliens: Bull. Inst. Monaco, No. 1121: 80 pp.), largely borrowed from bibliographies published in papers by J. W. Wells. Ranson has cited over 1500 articles published prior to 1958. References to other bibliographies are made at the end of this paper.

The increasing number of recent articles published on corals and coral reefs requires the issuing of a new bibliography, which takes up where Ranson left off. Because the study of carbonate and carbonate-secreting organisms has reached a high degree of research effort, another compilation will undoubtedly be required in a few years.

A bibliography on corals and coral reefs might include everything written on the subject, but this compilation is prejudiced toward the geological aspects of the subject, dealing mostly with Madreporarian

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* Contribution No. 586 from The Marine Laboratory, Institute of Marine Science, University of Miami.

** Institute of Marine Science, University of Miami, 1 Rickenbacker Causeway, Miami, Florida corals and modern reefs. Articles concerning other organisms are referred to only when the organisms affect the corals, their ecology, or their related sediments. Ancient reefs are cited only when they are associated with an area of present-day reef growth.

The papers are here categorized into specific subjects of certain technical or geographic problems. In cases where the paper cited deals with multiple subjects, the compiler has placed it in that category which seems most pertinent.

Over 80 percent of the citations have been annotated. Articles that were not read, either in complete or abstract form, are denoted by an asterisk (*). Annotations were excluded also from some citations in which the subject matter was explicit in the title.

ACKNOWLEDGEMENTS

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I. GEOLOGICAL FEATURES -- REEFS, ATOLLS AND THEIR SEDIMENTS

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1957 Nature and origin of atolls: Proc. 8th Pac. Sci. Congr. 3A: pp. 1009-1036. (A general treatment of locations and origins of atolls.)

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1961 Eustatic changes in sea-level: Physics and Chemistry of the Earth. Vol. 4: pp. 99-185. (This article is included in the bibliography because it logically presents the different mechanisms which have been explained as sea-level changes. An integrated theory is presented, and is supported by evidence gathered by various investigators. An extensive bibliography is included.)

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1957 Some geological processes at work on coral atolls: Trans. N. Y. Acad. Sci. Series II, Vol. 19; pp. 411-422. (The geological processes seen on a coral atoll are catagorized into constructive, stabilizing and destructive processes; each one is discussed. Different methods of islet formation are also discussed.)

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1959b The biology of corals: *Nat. Hist.*, Vol. 68(4): pp. 226-235. (A general discussion of the biology of corals. Relates Pacific coral reefs to West Indian reefs.)

RUSSELL, R. J., ed.

1961 Pacific Island terraces: Eustatic?: *Zeit. Geomorph.*, Supplement 3: 106 pp. (Contains 12 articles on elevated shorelines and terraces around the world. Of particular interest are:

Eustatic shorelines of Pacific islands, by H. T. Stearns.

Mauritius: River-mouth terraces and present eustatic sea stand, by W. G. McIntire.

Recent terraces of tropical limestone shores, by N. D. Newell.)

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SHEPARD, F. P.
1963 Submarine Geology: Harper Row, Publishers, New York. 557 pp. (A general review of coral reefs and atolls, with a section on the origin of atolls.)

STEERS, J. A.
1945 Coral reefs and air photography: Geog. Jour., Vol. 106: pp. 232-235. (Discusses different aspects of coral reefs which can be studied in greater detail and insight if aerial photography is used. These aspects include morphology, wave patterns, fringing reefs, etc.)

TEICHERT, C.
1958 Cold and deep-water coral banks: Bull. Amer. Asoc. Petrol Geol., Vol. 42(5): pp. 1064-1082. (Deep- and cold-water reefs can form "organic reefs" up to 200 feet thick and 1½ square miles in area. A few examples of modern and ancient reefs are given.)

WIENS, H. J.
1959 Atoll Development and morphology: Annals Assoc. Amer. Geogr., Vol. 49: pp. 31-54. (A theory of atoll development presented; linked to eustasy. Also discusses types of erosion, formation of groove-spur system, and the formation of beach rock.)

1961a The role of mechanical abrasion in the erosion of coral reefs and land areas: Proc. 9th Pac. Sci. Congr., 1957, No. 12: pp. 361-366. (Destructive agencies appear to play an extremely important role on the windward parts of coral reefs. Spurs and grooves are probably formed by mechanical erosion.)

1961b The evolution and destruction of atoll land: Proc. 9th Pac. Sci. Congr., 1957, No. 12: pp. 367-376. (The

effects of relative rises and falls of sea level on atoll origin and the evolution of atoll land are discussed. The text is mainly a review of previous workers, but personal observations are also added.)

1962 Atoll Environment and Ecology. Yale Univ. Press, New Haven. 532 pp. (A good basic reference, dealing mainly with the geography, ecology, geomorphology and meteorology of Pacific Atolls. In effect, it condenses American studies in the Pacific since 1945.)

YABE, H.
1942 Coral reef problem (in Japanese): Mem. Geol. Paleont. Inst. Tohoku Imp. Univ., Vol. 39: pp. 1-6. (Dominant growth is limited to the under-sea margin. Conclusions are reached from studies, made mainly by the author, on Pacific islands.)

1947 Coral reef problem: Science of the Earth, Vol. 2(3): pp. 41-42. (Discussion of the inter-relationship between Darwin's and Daly's hypotheses.)

YONGE, C. M.
1963 The biology of coral reefs; in Russell: Advances in Marine Biology. Academic Press Inc., London. pp. 209-260. (An excellent review of recent advances in the study of corals and coral reefs. The emphasis is on ecology.)

2 A. Indo-Pacific reefs and atolls

ALLDREDGE, L. R., F. KELLER, and W. J. DICHTEL
1954 Magnetic structure of Bikini Atoll: U. S. Geol. Surv. Prof. Paper 260-L: pp. 529-535. (Studies show a broad, negative anomally of 750 gammas over Bikini Atoll. A contour map shows the relative thickness to basement, interpreted from a model and field observations.)

ASAHINA, H.
1931 On the coral reefs of the South Seas: Jour, Geog. (Jap.), Vol. 43(508): pp. 337-349. (Average reef growth is about 4 centimeters/ year.)

ASANO, K.
1940 Limestones of the South Sea Islands under the Japanese Mandate: Jap. Jour. Geol. and Geog., Vol. 17(58).*

ASANO, K. (cont'd)
1942 Coral reefs in Oceania: *Mem. Geol. Paleont. Inst. Fac. Sci. Tohoku Imp. Univ.*, Vol. 39: pp. 27-45.*

AVIAS, J.
1959 Les récifs coralliens de la Nouvelle-Calédonie et quelques - uns de leur problèmes: *Bull. Soc. Geol. France* ser. 7, vol. 1: pp. 424-430. (The main reef is a barrier reef, but other reef types are present.)

BATES, M. and D. P. ABBOTT ✓
1958 *Coral Island. Portrait of an Atoll*. Charles Scribner's Sons Co., New York. 254 pp. (A popularized treatment of the scientific investigation of Ifaluk Atoll.)

BATTISTINI, R.
1959 Observations sur les récifs coralliens du sud-ouest de Madagascar: *Bull. Soc. Geol. France* ser. 7, Vol. 1: pp. 341-346. (A description of small lagoons formed by the coalescing of corals in Ramanetaka Bay. The fringing reef on the S. W. coast of Madagascar is trending towards a barrier reef because of present day conditions.)

BOSCHOFF, P. H.
1958 Development and constitution of the coral reefs in McNae and Kalk; in *A Natural History of Inhaca Island, Mozambique*. Johannesburg. pp. 49-56.*

CATALA, R.
1955 Iles basses corralliens et organisms marins du Pacific: *Bull. Soc. Zool. France*, Vol. 80(4): pp. 225-227. (resume of a general talk on the Gilbert archipelago.)

CHEVALIER, J.-P.
1964 Compte rendu des missions effectuées dans le Pacifique en 1960 et 1962, (Mission d'études des récifs coralliens de Nouvelle-Calendonie): *Cahiers du Pacif.*, No. 6: pp. 171-175. (Review of the basic objectives of the coral reef studies in the New Caledonia area.)

CHRISTIANSEN, S.
1963 Morphology of some coral-cliffs, Bismark Archipelago: *Geograf. Tidsskr.*, Vol. 62: pp. 1-23.*

CHUBB, L. J.
1957 The pattern of some Pacific island chains: *Geol. Mag.*, Vol. 94(3): pp. 221-228. (Suggests a series of growth stages developing from the volcano to atoll stage, moving progressively along the chain.) ✓

CLOUD, P. E., Jr.
1959 Geology of Saipan, Mariana Islands. Part 4. Submarine

Geology. *U. S. Geol. Surv. Prof. Paper*. 280-K: pp. 361-445. ("Description and interpretation of the submarine topography and of the sediments, biotas, and morphology of the reef complex adjacent to a geological diverse tropical island." The spurs and grooves seem to be erosional features.)

CLOUD, P. E., Jr., R. G. SCHMIDT, and H. W. BURKE

1956 Geology of Saipan, Mariana Islands. Part 1. General geology: *U. S. Geol. Surv. Prof. Paper* 280-A: pp. 1-126. (About 1500 feet of sediments, Miocene through Recent, overlie an andesitic volcano. Later limestones include reef complexes.)

COLE, W. S.

1957a Larger Foraminifera from Eniwetok Atoll drill holes: *U. S. Geol. Surv. Prof. Paper* 260-V: pp. 743-784. (62 species are identified; most were deposited in shallow water. Stratigraphic correlations are made between Eniwetok, Bikini, and Saipan.)

1957b Geology of Saipan, Mariana Islands. Part 3. Larger Foraminifera: *U. S. Geol. Surv. Prof. Paper* 280-I: pp. 321-360. (Tertiary fauna are listed and discussed.)

1963 Tertiary larger Foraminifera from Guam: *U. S. Geol. Surv. Prof. Paper* 403-E: 28 pp. (The distribution of diagnostic Tertiary species is given, along with their correlation to Saipan and the Eniwetok drill holes.)

COLE, W. S. and J. BRIDGE

1953 Geology and larger Foraminifera of Saipan Island: *U. S. Geol. Surv. Prof. Paper* 253: 45 pp. (A general study of Saipan Island; the oldest exposed rocks are Eocene lava flows. Some of the terraces on the island are uplifted reefs. A present-day fringing reef is, in places, quite healthy.)

CROSSLAND, C.

1911 Red Sea coral reefs: *Jour. Linn. Soc. Zool.*, Vol. 31(208): pp. 265-286. (Regional uplift has affected the coral reefs as well as the physiography of the area. Modern reef distribution is related to currents and sediment movement.)

CUSHMAN, J. A.

1942 A report on the samples obtained by the boring at Heron Island, Great Barrier Reef, Australia: *Great Barrier Reef Exped. Sci. Rept.*, Vol. 5: pp. 112-119.*

DORAN, E., Jr.
1960 Report on Tarawa Atoll, Gilbert Islands: *Atoll Res. Bull.*, No. 72: 54 pp. (Includes a short discussion of the topography with a series of charts and aerial photos.)

DORBIN, M. B.
1950 Submarine geology of Bikini Lagoon as indicated by depression of water-borne explosive waves: *Bull. Geol. Soc. Amer.*, Vol. 61: pp. 1091-1118. (Techniques and results of sound transmission and measures are given. A *Halimeda* facies change in the central portion of the lagoon explains the increase in sound velocity.)

DORBIN, M. B. and B. PERKINS, Jr.
1954 Seismic studies of Bikini Atoll: *U. S. Geol. Surv. Prof. Paper* 260-J: pp. 487-506. (Findings indicate a subsidence of between 3000 and 13,000 feet. The basement surface of the atoll seems to have more relief than guyots.)

DOUMENGE, F.
1961 Observations à propos des formations coralliennes de l'ile Wallis: *Bull. Assoc. Geog. Franc.*: pp. 186-196.*

EMERY, K. O.
1956 Sediments and water of Persian Gulf: *Bull. Amer. Assoc. Petroleum Geol*. Vol. 40(10): pp. 2354-2383. (Coral and oolite composes only a small amount of the sediment in the Persian Gulf. Reef locations are shown; charts also show distribution of salinity, temperature and sediment characteristics.)

1962 Marine geology of Guam: *U. S. Geol. Surv. Prof. Paper* 403-B: pp. B1-B76. (A detailed study of the reefs and sediments in the Guam area. Typhoon effects and beach studies are also included.)

FAIRBRIDGE, R. W.
1953 The Sahul Shelf, northern Australia; its structure and geological relationships: *Jour. Roy. Soc. Western Aust.*, Vol. 37: pp. 1-33.*

FAIRBRIDGE, R. W. and C. TEICHERT
1948 Some coral reefs of the Sahul Shelf: *Geog. Rev.*, Vol. 38(2): pp. 222-249. (Mainly an analysis of aerial photos of the reef area. Origins of the reef owed to subsidence with tilting, eustasy, and/or faulting.)

FAIRBRIDGE, R. W. and H. B. STEWART, Jr.
1960 Alexa Bank, a drowned atoll on the Melanesian Border

Plateau: *Deep Sea Res.*, Vol. 7: pp. 100-116. (General trends of the area are described. Alexa Bank has some living pinnacles of reef coral, but most of the coral is dead. The raised rim feature surrounding a mild depression, and the generally steep outer slopes suggest a drowned atoll.)

FISCHER, P. H.
1961 Coup d'oeil sur la Grande-Barrière d'Australie et en particulier sur un récif du group du Capricorne: *Cahiers Pacif.*, No. 3: pp. 52-74. ("...a brief glimpse at the Great Barrier Reef and its reefs." Mainly concerned with geomorphology and a review of the literature.)

FOSBERG, F. R., *et al*.
1956 Military geography of the Northern Marshalls: U. S. Army, Chief Eng. *Intelligence Div.,Engineer Headqtrs. U. S. Army, Far East and Eighth U. S. Army*. 320 pp. (Contains information that has not been published otherwise. Includes sections on the general geography, climate, geology and ecology, plus others. Most of the northern Marshalls are covered.)

GARDINER, J. S.
1900 The atoll of Minikoi: *Proc. Camb. Phil. Soc.*, Vol. 11: pp. 22-26.*

GILLETT, K. and F. McNEILL
1959 *The Great Barrier Reef and adjacent isles*. Coral Press, Paddington, Sydney, Australia. 194 pp. (Mainly descriptive, but does contain some excellent pictures of coral reefs and corals. Also discusses some of the general geology of the area.)

GRESSITT, J. L.
1952 Description of Kayangel Atoll, Palau Islands: *Atoll Res. Bull.*, No. 14: 6 pp. (A very general description of the atoll. Includes a bathymetric chart showing locations of coral heads.)

1953 Notes on Ngaruangl and Kayangel Atolls, Palau Islands: *Atoll Res. Bull.*, No. 21: 5 pp. (A very brief description of the morphology of Ngaruangl Atoll.)

GROVER, J. C.
1960 The geology of Rennell and Bellona, the great uplifted atolls on the edge of the Coral Sea; in T. Wolff: *The Natural History of Rennell Island, British Solomon Islands, Vol 3. Botany and Geology*. pp. 103-119. (The rim of coral

limestone is 360 feet above sea level; fossil algae and Foraminifera are listed.)

GUILCHER, A.

1956 Etude géomorphologique des récifs coralliens du nordouest de Madagascar: Ann. Inst. Oceanog. (Paris), No. 33: pp. 65-136.*

1958 Mise au point la géomorphologie des récifs coralliens de Madagascar et dépendances. Mem. Inst. Sci. Madagascar, Ser. F - Oceanog., No. 2: pp 89-115. (Maximum growth was post-glacial; present growth is peripheral.)

1959 Les récifs coralliens à petits lagons multiples de la baie Ramanetaka (Côte nord-ouest de Madagascar): Bull. Soc. Geol. France. Ser. 7, Vol. 1: pp. 337-340. (A description of small lagoons formed by the coalescing of corals in Ramanetaka Bay.)

1963 Quelques caracteres des récifs-barrieres et de leurs lagons: Bull. Assoc. Geogr. France, Vol. 314-315: pp. 2-16. (Abstracted in Cahiers du Pacif., no. 6: p. 200). (The origin of double barrier reefs, faros and spurs and grooves are discussed. Algal ridges were not found on the barrier reefs of New Caledonia.)

GUILCHER, A. and L. BERTHOIS

1955 Les recifs coralliens du nord du Banc Farsan, Mer Rouge: Ann. Inst. Oceanog. (Paris), No. 30: pp. 1-100.*

GUILCHER, A. L., L. BERTHOIS, R. BATTISTINI and P. FOURMANOIR

1958 Les recifs coralliens des iles Radama et de la baie Ramanetaka (cote nord-ouest de Madagascar; etude géomorphologique et sedimentologique: Mem. Inst. Sci. Madagascar, Ser. F. - Oceanog., No. 2: pp. 117-199.*

HAEBERLE, F. R.

1952 The d'Entrecasteaux Reef group: Amer. Jour. Sci., Vol. 250: pp. 28-34. (It is probable that this reef group is an excellent example of an antecedent platform origin.)

HAMILTON, E. L.

1956 Sunken islands of the Mid-Pacific mountains: Geol. Soc. Amer. Memoir 64: 97 pp. (Cretaceous reef corals were dredged from the tops of guyots. This supports Darwin's Subsidence Theory for the formation of atolls.)

HAMILTON, E. L. and R. W. REX

1959 Lower Eocene phosphatized Globigerina ooze from Sylvania

Guyot: U. S. Geol. Surv. Prof. Paper 260-W: pp. 785-798. (Sylvania Guyot has a flat top at 705 fathoms. It is probable that Sylvania was eroded to a level bank and subsequently subsided.)

HANZAWA, S.

1940 On the problems of coral reefs of the South Sea Islands: Science of the Ocean,: pp. 470-485. (Among the problems discussed are the classification of reefs, the origin of spur-groove zones, the formation of islands on atolls, and the origins of beach rock by evaporation of sea water.)

JOHNSON, J. H.

1957 Geology of Saipan, Mariana Islands. Part 2. Petrography of the limestones: U. S. Geol. Surv. Prof. Paper 280-6: pp. 177-187. (The limestones are mainly algal-foraminiferal and coral-algal, indicative of old reefs. Excellent plates are included, to illustrate the different types of limestones.)

1957 Geology of Saipan, Mariana Islands. Part 3. Calcareous algae: U. S. Geol. Surv. Prof. Paper 280-E: pp. 209-246. (Includes recent algae.)

1962 Comparison of the calcareous algal floras of recent and fossil reefs: Proc. 9th Pac. Sci. Cong., 1957, Vol. 4: pp. 156-160. (Includes distribution charts of recent and Eocene coralline algae in the Pacific area as well as a chart showing the geologic range of recent coralline algae genera.)

1964 Fossil and recent calcareous algae from Guam: U. S. Geol. Surv. Prof. Paper 403-G: 40 pp. (68 species from 16 genera are described along with ecological and stratigraphic distributions. All formations are abundant in algae.)

KOHN, A. J.

1964a Notes on Indian Ocean atolls visited by the Yale Seychelles Expedition: Atoll Res. Bull., No. 101: 12 pp.

1964b Notes on reef habitats and gastropod molluscs of a lagoon island at North Male Atoll, Maldives: Atoll Res. Bull., No. 102: 5 pp. (Lagoon islands form from faros. Observations support this theory.)

KUENEN, P. H.

1954 Eniwetok drilling results: Deep-Sea Res., Vol. 1: pp. 187-189.*

1956 Coral reefs of Indonesia: Pac. Sci. Congr. 8th, Philippines, Vol. 2A: pp 851-853. (Summarizes research since 1947, and current problems.)

LADD, H. S.
1956 Coral reef problems in the open Pacific: *Pac. Sci. Congr. 8th, Philippines*, Vol. 2A: pp. 833-848. (Discussion of work carried out on coral reefs since 1945.)

LADD, H. S. and S. O. SCHLANGER
1960 Drilling operations on Eniwetok Atoll: *U. S. Geol. Surv. Prof. Paper*: 260-Y: pp. 863-903. (A summary of the lithology of 21 shallow wells and 3 deep wells. Compares the subsurface geology of Eniwetok with drill holes data from other areas.)

MA, T. Y. H.
1957 Marine terraces in the western Pacific and the origin of coral reefs: *Oceanographica Sinica*, Vol. 5(2). (Marine terraces and reefs are related to the pauses in crustal movements.)

McKEE, E. D.
1958 Geology of Kapingamarangi Atoll, Caroline Islands: *Bull. Geol. Soc. Amer.*, Vol. 69: pp. 241-278. (Includes descriptions of atoll framework, sediments, reef and lagoonal structures, soils, and ground water.)

McNEILL, F.
1955 Coral paradise of One Tree Island: *Austral. Mus. Mag.*, No. 11: pp. 404-408.*

MASON, A. C., *et al.*
1956 Military geology of Palau Islands, Caroline Islands: U. S. Army, Chief Eng., *Intelligence Div., Headqtrs. U.S. Army Forces Far East (Tokyo)*: 285 pp. (cf. Tracey *et al.*, 1964.)

NESTEROFF, W. D.
1955 Quelques résultats géologiques de la campagne de la "Calypso" en Mer Rouge (1951-1952): *Deep-Sea Res.*, Vol. 2(4): pp. 274-283. (Origin of the Red Sea and a discussion of the origin and structure of coral reefs in the Red Sea.)

NIERING, W. A.
1961 Observations on Puluwat and Gaferut, Caroline Islands: *Atoll Res. Bull.*, No. 76: 10 pp. (A very brief discussion of the geology of the island, supplemented by an aerial photo.)

NUGENT, L. W.
1948 Elevated phosphate islands in Micronesia: *Bull. Geol. Soc. Amer.*, Vol. 59(10): pp. 977-994. (Describes 8 elevated atolls. The general geology and morphology affords agreement with the Glacial Control Theory.)

PICHON, M.

1962 Note preliminaire sur la topographie et la géomorphologie des récifs coralliens de la région de Tulear (Madagascar): *Rec. Trav. Stn. Mar. Endoume Suppl.*, No. 1: pp. 153-168.*

1963 Rôle de la subsidence dans la formation des récifs-barriere sur la côte sud-ouest de Madagascar (région de Tulear): *C. R. Acad. Sci. Paris*, Vol. 256(4): pp. 980-981.*

PIGGOTT, C. J.

1961 Notes on some of the Seychelles Islands, Indian Ocean: *Atoll Res. Bull.*, No. 83: 10 pp. (Classifies the islands according to their morphology, and discusses the geology of several.)

POPE, E. C.

1962 New Caledonia, the coral-ringed island: *Australian Nat. Hist.*, Vol. 14(1): pp. 3-11. (Regional coral geology is included.)

RAITT, R. W.

1954 Seismic refraction studies of Bikini and Kwajalein Atolls: *U.S. Geol. Surv. Prof. Paper* 260-K: pp. 507-528. (Seismic velocities beneath Bikini lagoon vary laterally as well as vertically. This gives an insight into the history of the atoll.)

1957 Seismic refraction studies of Eniwetok Atoll: *U. S. Geol. Surv. Prof. Paper* 260-S: pp. 685-698. (Six layers of rock were recorded. The first two are carbonate; the rest were non-sedimentary. The sixth layer, 16-17 kilometers below sea level, is probably just below the Mohorovicic discontinuity.)

RANSON, G.

1958 Coraux et récifs coralliens. Observations sur les îles coralliennes de l'archipel des Tuamotu (Océanie Française): *Cahiers Pacif.*, No. 1: pp. 15-36. (Different theories of atoll formation are reviewed, followed by a description of the elevated and modern reefs in the Tuamotus. Lagoon formation and the history of the Tuamotus are also mentioned.)

1962 *Missions dans le Pacifique. Récifs coralliens. Hûitres perlières.* Paris, Ed. Lechevalier, pp. 1-99. (Reviewed in *Cahiers Pacif.*, No. 5, p. 87, and in *Atoll Res. Bull.*, No. 100, pp. 4-5.) (Appears to be similar to the above article.)

REVELLE, R., *et al.*

1953 Shipboard report, Capricorn Expedition: *Scripps Inst. Ref.* 53-15: 60 pp. (The general description of the reefs and atolls visited. Of special interest is a photo of the coral on Falcon Bank, which has only recently submerged under water.)

SACHET, M.-H.
1962a Geography and land ecology of Clipperton Island: Atoll Res. Bull., No. 86: 115 pp. (Weather and ocean currents are mentioned. Description of the different zones on the atoll; the Lithothamnion ridge is absent, and the lagoon is fresh water.)

1962b Monographie physique et biologique de l'île Clipperton: Ann. Inst. Oceanogr. n.s., Vol. 40(1): 107 pp. (Basically this is a French translation of Sachet, 1962a. But it does include photos of this "almost atoll".)

SCHLANGER, S. O.
1963 Subsurface geology of Eniwetok Atoll: U. S. Geol. Surv. Prof. Paper 260 BB: pp. 991-1066. (Contains sections on the carbonate mineralogy, petrology of the basement basalt, and dating of the carbonate rocks. The subsurface geology is compared to similar areas that have been studied.)

1964 Petrology of the limestones of Guam: U.S. Geol. Surv. Prof. Paper 403-D: 52 pp. (The limestones of Guam were formed predominantly by reef growth. The components of the entire Tertiary reef facies are essentially the same. 21 plates of petrographic illustrations are included.)

SHIPEK, C. J.
1962 Photographic survey of sea floor on southwest slope of Eniwetok Atoll: Bull. Geol. Soc. Amer., Vol. 73(7): pp. 805-812. (The observed rippled sediments suggest strong water movements.)

SHOR, G. C., Jr.
1964 Thickness of coral at Midway Island: Nature, Vol. 201(4925): pp. 1207-1208. (The results of a brief seismic refraction survey show a thickness of coral rock of about 370 meters.)

SHOR, G. C., Jr. and D. D. POLLARD
1963 Seismic investigations of Seychelles and Saya de Malha Banks, northwest Indian Ocean: Science, Vol. 142(3588): pp. 48-49. (The two areas are underlain with granite, and are capped with coral.)

SQUIRES, D. F.
1959 Results of the Puritan-American Museum of Natural History expedition to western Mexico. 7. Corals and coral reefs in the Gulf of California: Bull. Amer. Nat. Hist., Vol. 118(7): pp. 367-432. (Ecology of the reefs discussed; the fauna resembles the panamic faunal types and, to a lesser extent, the Indo-Pacific fauna. Formations are young due to the tectonic activity of the area.)

SUGIYAMA, T.

1942 Reef-building corals of Yap island and its fringing reefs: Mem. Paleont. Inst. Fac. Sci. Tohoku Imp. Univ., Vol. 39: pp. 7-26. (Description of the coral reefs of Yap, including a list of 75 species of coral.)

SWARTZ, J. H.

1958 Geothermal measurements, Eniwetok and Bikini Atolls: U. S. Geol. Surv. Prof. Paper 260-U: pp. 711-741. (The thermal properties of the atolls are largely the result of cooling by the adjacent sea water. Only in one well did the temperature increase at depth; the rate was 20°C/kilometer.)

1962 Some physical constants for the Marshall Islands area: U. S. Geol. Surv. Prof. Paper 260-AA. (Gives some geophysical constants for different sediment types encountered.)

TAYAMA, R.

1951 Geology of Angaru Island: Tohoku Univ. Inst. Geol. and Paleont., Short Papers, No. 3: pp. 91-108. (A raised atoll that went through stages of atoll, barrier reef and fringing reef.)

TEICHERT, C.

1950 Late Quaternary changes in sea-level at Rottnest Island, Western Australia: Proc. Roy. Soc. Victoria, Vol. 59(2): pp. 62-79. (Pleistocene coral reefs are overlain with aeolian dune limestone.)

TODD, R.

1957 Geology of Saipan, Mariana Islands. Part 3. Smaller Foraminifera: U. S. Geol. Surv. Prof. Paper 280-H: pp. 265-313. (Includes recent lagoonal fauna.)

TODD, R. and D. LOW

1960 Smaller Foraminifera from Eniwetok drill holes: U. S. Geol. Surv. Prof. Paper 260-X: pp. 799-861. (265 species are identified. Stratigraphic correlations agree with Cole, 1957, who stated that Eniwetok's formations are correspondingly shallower than Bikini's.)

TRACEY, J. I., D. P. ABBOTT, and T. ARNOW

1961 Natural history of Ifaluk Atoll; Physical environment: Bull. B. P. Bishop Mus., No. 222: pp. 1-75. (A summary of geologic and other physical features of Ifaluk Atoll.)

TRACEY, J. I., S. O. SCHLANGER, J. T. STARK, D. B. DOAN, and H. G. MAY

1964 General geology of Guam: U. S. Geol. Surv. Prof. Paper 403-A: 104 pp. (A study of the stratigraphy and geologic history of Guam. Also includes a chapter on the modern reefs.)

TRACEY, J. I., et al.

1959 Military geology of Guam, Mariana Islands. Part I. Description of terrain and environment. Part II. Engineering aspects of geology and soils: U. S. Army, Chief Eng., Intelligence Div., Headqtrs. U. S. Army Pacific (Tokyo): 282 pp. (cf. Tracey et al., 1964.)

VERSTAPPEN, H. T.

1953 Early and recent research on the coral island in the Bay of Djakarta: Tijdschr. Konink. Nederland. Aardrijkskundig Genootschap, Amsterdam, Vol. 70: pp. 472-478.*

1960 On the geomorphology of raised coral reefs and its tectonic significance: Zeit. Geomorph., Vol. 4(1): pp. 1-28. (A study of raised reefs, primarily in the Moluccas. Tectonic uplift explains the thinness of the reefs as well as the terracing.)

WIENS, H. J.

1956 The geography of Kapingamarangi Atoll in the eastern Carolines: Atoll Res. Bull., No. 48: 86 pp. (Includes history, topography, currents, climate, and a description of the individual islands.)

1957 Field notes on atolls visited in the Marshalls, 1956: Atoll Res. Bull., No. 54: 23 pp. (Contains scattered, general descriptions of morphologic forms the author observed on various atolls.)

ZANEVELD, J. S. and H. T. VERSTAPPEN

1952 A recent investigation about the geomorphology and the flora of some coral islands in the Bay of Djakarta: Jour. Sci. Res. Djakarta, Vol. 1(2): pp. 38-43; Vol. 1(3): pp. 58-66.*

2B. Atlantic Reefs and Atolls

ALLEN, J. R. L. and J. W. WELLS

1962 Holocene coral banks and subsidence in the Niger Delta: Jour. Geol., Vol. 70(4): pp. 381-397. (Banks of dead ahermatypic corals are compared with other areas.)

BOYD, D. W., L. S. KORNICKER and R. REZAK

1962 Recent algal bioherms near Cozumel Island, Mexico (abs.): Geol. Soc. Amer. Spec. Paper, No. 73: pp. 121-122. (Coralline algae are seen to build a series of microatolls, from 12 to 25 feet in diameter. Corals are not common. The species of algae are listed.)

BROOKS, H. K.

1962 Reefs and bioclastic sediments of the Dry Tortugas (abs.): Geol. Soc. Amer. Spec. Paper, No. 73: pp. 1-2. (Dry Tortugas is not an atoll, but rather a series of banks, shoals and reefs that rise from a limestone platform. Live coral is sparse.)

de ANDRADE, O.

1958 O recife anular das Rocas, um registro de recentes variacoes eustaticas no Atlantico equatorial: Comm. 13th Assembl. Assoc. Geog. Brazil.*

DE BUISONJE, P. H.

1964 Marine terraces and sub-aeric sediments on the Netherlands Leeward Islands, Curacao, Aruba and Bonaire, as indicators of Quaternary changes in sea level and climate. I and II: Proc. Koninkl. Nederl. Akad. Wetenschappen, Series B, Vol. 67(1): pp. 60-79. (Observations are made on four "Quaternary" terraces, ranging in elevation from 10 meters to nearly 200 meters. The terraces appear to be elevated coral reefs and lagoonal deposits.)

DE BUISONJE, P. H. and J. I. S. ZONNEVELD

1960 De Kustvormen van Curacao, Aruba en Bonaire: Natuurw. Werkgroep Nederl. Antillen, No. 11: pp. 121-144. ("The islands of Curacao, Aruba and Bonaire are surrounded by coasts that either have the character of cliffs cut in solid coral limestones, or built up of loose coral debris and coral sands." The different types of shoreline are discussed; some mention is given to present-day coral reefs.)

DORAN, E.

1954 Land forms of Grand Cayman Island, British West Indies: Texas Jour. Sci., Vol. 6: pp. 360-377. (Deals with the physiography, geology, and geologic history of Grand Cayman Island.)

1955 Land forms of the southeast Bahamas: Dept. Geog. Univ. Texas Publ., No. 5509: 38 pp. (Excellent charts made from aerial photographs and personal observations. Various geomorphic forms are discussed.)

EMERY, K. O.

1962 Coral reefs off Veracruz, Mexico: Geofisica Internacional, Vol. 3(1): pp. 11-17. (The reefs resemble patch reefs and are so classified. Sediment analyses are given; the percentage of coral detritus in the sediments of the area is greater than similar areas in the Pacific Ocean.)

FOSBERG, F. R.

1962 A brief study of the cays of Arrecife Alacran, a Mexican atoll: Atoll Res. Bull., No. 93: 25 pp. (Although most of this paper concerns the vegetation of the area, there is mention of the physiography and climate. Also included is a comparison between Alacran and a Pacific atoll.)

GOREAU, T. F.

1958. Buttressed reefs in Jamaica, British West Indies: Proc. XVth Intern. Congr. Zool., p. 250. (Buttresses examined seem to indicate a formation by coral growth, not erosion. There appears to be no correlation between the prevailing winds and the lineation of the buttresses.)

1961 The structure of the Jamaican reef communities. Geological aspects: New York Zool. Soc., Dept. Marine Biochem. and Ecology. 14 pp. (A series of submarine terraces, drowned reefs and submarine canyons are reported. The modern reef is up to 35 feet thick.)

1964 Fore-reef slope: structure, sediment, and community relationships (abs.): Geol. Soc. Amer., Program, 1964 Ann. Meeting, p. 76. (Mostly reviews previous papers. Little sediment accumulates on the fore-reef slope; most is transported to deeper waters.)

HOFFMEISTER, J. E. and H. G. MULTER

1964 Growth-rate estimates of a Pleistocene coral reef of Florida: Bull. Geol. Soc. Amer., Vol. 75(4): pp. 353-358. (By using the rate of growth of Montastrea annularis, a 7-foot vertical section of the Key Largo limestone has been estimated to have taken 250 to 500 years to form.)

HOSKIN, C. M.

1963 Recent carbonate sedimentation on Alacran Reef, Yucatan, Mexico: Nat. Acad. Sci.-Nat. Res. Coun. Publ. 1089, 160 pp. (A rather complete study of the sedimentary characteristics of Alacran Reef. 19 biotopes are recognized on the basis of grain size and composition.)

JORDAN, G. F.

1952 Reef formation in the Gulf of Mexico off Apalachicola Bay, Florida: Bull. Geol. Soc. Amer., Vol. 63(7): pp. 741-744. (Banks have been found to be capped with coral.)

KAYE, C. A.

1959a Shoreline features and Quaternary shoreline changes, Puerto Rico: U. S. Geol. Surv. Prof. Paper 317-B: pp. 49-140. (The fringing coral reefs are typical Caribbean reefs; a brief description is included. The general chemical and physical features of the various types of beach rock are considered.)

KAYE, C. A. (cont'd)

1959b Geology of Isla Mona and the age of Mona Passage: U. S. Geol. Surv. Prof. Paper 317-C: pp. 141-178. (The limestone that composes Isla Mona is a Miocene reef-limestone. The elevated reefs are discussed.)

KORNICKER, L. S.

1963 The Bahama Banks: a "living" fossil environment: Jour. Geol. Education, Vol. 11(1): pp. 17-25. (A review of some literature and a general insight into the geology of the Bahamas.)

KORNICKER, L. S., F. BONET, R. CANN, and C. M. HOSKIN

1959 Alacran Reef, Campeche Bank, Mexico: Publ. Inst. Marine Sci., Univ. Texas, Port Aransas, Vol. 6: pp. 1-22. (Description of the reefs, sediment and fauna of this "shelf atoll".)

KORNICKER, L. S. and D. W. BOYD

1962a Shallow-water geology and environments of Alacran Reef complex, Campeche Bank, Mexico: Bull. Amer. Assoc. Petroleum Geol., Vol. 46(5): pp. 640-673. (The ecology of the reef is discussed, along with the ecologic zonations of the reef-building organisms. A discussion of the application to the study of fossil reefs follows.)

1962b Biogeology of a living coral reef complex on Campeche Bank: Guide Book to Field Trip to Peninsula of Yucatan. New Orleans Geol. Soc., Feb. 1-5, 1962. pp. 73-84. (The main contributors to the framework, sediment, and cementing agents are discussed. The general ecology and geology of the reef are also discussed.)

LeCONTE, J.

1883 The reefs, keys and peninsula of Florida: Science, Vol. 2: p. 764.*

LEWIS, J. B.

1960 The coral reefs and coral communities of Barbados, West Indies: Canadian Jour. Zool., Vol. 38(6): pp. 1133-1145. (Form, development and coral growth are discussed. Species are located in definite zones; the windward reefs are not actively growing.)

LOGAN, B. W.

1961 Coral reef and bank communities of the Campeche Shelf, Yucatan, Mexico (abs.): Geol. Soc. Amer. Spec. Paper, No. 68: p. 218. (Two communities have colonized rocky mounds on the shelf area: the primary reef corals are in shallow water, the ahermatypic corals in deeper water.)

LOGAN, B. W. (cont'd)

1962 Submarine topography of the Yucatan Platform: Guide Book to Field Trip to Peninsula of Yucatan. New Orleans Geol. Soc., Feb. 1-5, 1962. (A short discussion of the submarine terraces, shelf mounds, and the location of coral reefs and other banks.)

LUDWICK, J. C. and W. R. WALTON

1957 Shelf-edge, calcareous prominences in northeastern Gulf of Mexico: Bull. Amer. Assoc. Petroleum Geol., Vol. 41(9): pp. 2054-2101. ("Fossil" reefs, now in 40-55 fathoms of water, are related to pre-existing lower stands of sea level.)

MOORE, D. R.

1958 Notes on Blanquilla Reef, the most northerly coral formation in the western Gulf of Mexico: Publ. Inst. Marine Science, Univ. Texas, Port Aransas, Vol. 5: pp. 151-155. (Live coral is rare on the windward (east) side but is common on the leeward side; because of long-fetch, storm waves can cause great destruction.)

MOORE, D. R. and H. R. BULLIS, Jr.

1960 A deep-water coral reef in the Gulf of Mexico: Bull. Marine Sci. Gulf and Carib., Vol. 10(1): pp. 125-128. (The first deep-water reef reported in the West Indies, at a depth of 280-300 fathoms.)

NEWELL, N. D.

1958a American coral reefs: Trans. New York Acad. Sci., Ser. 2, Vol. 21(2): pp. 125-127. (Principal biotic zones, structures, and the functions of the reefs are discussed.)

1958b American coral seas: Proc. XVth Intern. Congr. Zool., pp. 251-252. (Coral growth in the Florida-Bahamas area first terminated on the Blake Plateau probably in the Miocene. Cooling waters caused a regression of the reefs to Florida and the Bahamas, until most all reefs were killed. Reefs have only recently been re-established.)

1959 West Atlantic coral reefs: Reprints Ist Intern. Ocean. Congr. pp. 286-287. (Abstracts work published previously.)

1960 Marine planation of tropical limestone islands: Science, Vol. 132: pp. 144-145. (Sea level in the Caribbean seems to be currently the highest since the Pleistocene; there has been no recent planation. The platforms, therefore, represent an equilibrium between the upper limits of carbonate deposition and the lower limits of intertidal erosion.)

NEWELL, N. D., J. IMBRIE, E. G. PURDY, and D. L. THURBER
1959 Organism communities and bottom facies, Great Bahama Bank: *Bull. Amer. Mus. Nat. Hist.*, Vol. 117(4): pp. 177-228. (A general discussion of the bottom facies and communities. The coral zonations and dominant species are described, with insights into the reasons for limited growth.)

OTTMANN, F.
1963 "l'Atoll das Rocas" dans l'Atlantique sud tropical: *Revue Geog. Phys. et Geol. Dynam.*, Vol. 5(2): pp. 101-107. (The atoll appears to be more algologic than coralline. Traces of the last transgressive period of the Quaternary can be seen at +2 meters.)

PARENZAN, P.
1957 Formazioni coralligene mediterranee e loro biologia: *Boll. Zool.*, Vol. 24(2): pp. 287-312.*

PARKER, G. C., C. E. FERGUSON, S. K. LOVE, *et al.*
1955 Water resources of southeastern Florida: *U. S. Geol. Surv. Water-Supply Paper*, No. 1255: 965 pp. (Includes a rather extensive description of the Tertiary and Quaternary Formations in southeastern Florida.)

PURDY, E. G. and R. K. MATTHEWS
1964 Structural control of recent calcium carbonate deposition in British Honduras (abs.): *Geol. Soc. Amer., Program, 1964 Ann. Meeting*, p. 157. (The distribution of reefs is related to Pleistocene topographic highs, which in turn are related to the underlying structure. The Pleistocene topography has induced differential sedimentation rates, which have tended to accentuate the relief.)

PURI, H. S. and R. O. VERNON
1959 Summary of the geology of Florida and a guidebook to the classic exposures: *Fla. State Geol. Surv. Spec. Publ.*, Vol. 5: 255 pp. (Descriptions of geologic formations in Florida, from Pre-Cambrian to the present; includes present-day reefs.)

SCHUSTER-DIETERICHS, O.
1956 Auf einer korallen-insel des Karribischen Meeres: *Nature Volk.*, Vol. 86: pp. 376-380.*

SHINN, E. A.
1963 Spur and groove formation on the Florida Reef Tract: *Jour. Sed. Pet.*, Vol. 33(2): pp. 291-303. (The ecologic zonations in the Florida Keys are considered. The origin of the spur-groove complex is related to biologic differentiation in the growth of wave-oriented *Acropora palmata*.)

SQUIRES, D. F.
1963 Calcareous shelf-edge prominences off the Orinoco River of South America (abs.): *Geol. Soc. Amer. Spec. Paper*, No. 76: p. 155. (Contrary to previous reports, "there is no evidence to indicate that the wall or prominences were once a coral reef, and reef corals presently make no contribution to their growth.")

STEERS, J. A.
1940 The cays and Palisadoes, Port Royal, Jamaica: *Geog. Rev.*, Vol. 30: pp. 279-296. (Coral, although abundant, has not fused together to form massive reefs; *Halimeda* is a prominent component of the sediment. Significant changes may occur due to storms.)

STEERS, J. A., V. J. CHAPMAN, and J. A. LOFTHOUSE
1940 Sand cays and mangroves in Jamaica: *Geog. Jour.*, Vol. 96: pp. 305-328. (Formation of the cays, the beach rock and various other structures are discussed. Sediments are anchored on the cays by vegetation.)

STETSON, T. R., D. F. SQUIRES, and R. M. PRATT
1962 Coral banks occurring in deep water on the Blake Plateau: *Amer. Mus. Novitates*, No. 2114: 39 pp. (Studies were carried out by PDR tracings, bottom photography and bottom sampling; the "reefs" are compared with similar studies.)

STEWART, H. B., Jr., A. D. RAFF, and E. L. JONES
1961 Explorer Bank - a new discovery in the Caribbean: *Bull. Geol. Soc. Amer.*, Vol. 72(8): pp. 1271-1274. (The bank rises 1000 fathoms to a depth of 15 fathoms. Magnetic surveys indicate a possible origin similar to Pacific atolls.)

STODDART, D. R.
1962 Three Caribbean atolls: Turneffe Islands, Lighthouse Reef, and Glovers Reef, British Honduras: *Atoll Res. Bull.*, No. 87: 149 pp. (Each atoll is described in detail. Sediments types, coral fauna, and ecologic zonations are discussed. Author presents a theory on the formation of the atoll cays, and other general structures.)

THORPE, J. E., and D. R. STODDART
1962 A summary of reef work of the Cambridge Expedition to British Honduras of 1959-1960: *Geog. Jour.* Vol. 128: pp. 158-173. (Most of the article is by Stoddart, who condenses his 1962 *Atoll Res. Bull.* article into this brief paper. An interesting discussion follows, primarily concerned with beach rock formation.)

VERMEER, D. E.

1959 The Cays of British Honduras: Dept. Geog., Univ. Calif., Berkeley.*

WILSON, R. L., R. E. BERGENBACK, and C. P. FINLAYSON

1961 Fossil coral reefs, Fresh Creek, Andros Island, Bahamas (abs.): Geol. Soc. Amer. Spec. Paper, No. 68: p. 82. (Fossil patch reefs, overlain by oolitic limestone, extend at least 1/2 mile from the present shoreline.)

ZANEVELD, J. S.

1957 Micro-atolls in the Netherlands Antilles: Rept. on Inter-Island Marine Biol. Conf., Inst. Marine Biol., Univ. Puerto Rico. pp. 18-19. (Sedimentation, not exposure to air, causes micro-atolls.)

1958 A lithothamnion bank at Bonaire (Netherland Antilles): Blumea (Supplement), Vol. 4: pp. 206-219.*

ZANS, V. A.

1958a Recent coral reefs and reef environments of Jamaica: Geo Notes (Kingston), Vol. 1: pp. 18-25. (Abstracted in Trans. 2nd Geol. Congr. Mayaguez. p. 58.) (Discusses the different ecologic zones of Jamaica, and their relative locations. The reefs are poorly developed because of their comparative youth - Post-Pleistocene.)

1958b The Pedro Cays and Pedro Bank: Rept. on the Survey of the Cays. 1955-57; Kingston Geol. Surv. Dept. Bull., Vol. 3: pp. 1-47. (It is hypothesized that Pedro Bank is a slightly tilted block upon which reef development has been added. Rampart zones, probably hurricane formed, are prominent on the seaward portions of the reef cay complexes. Petrology of the Pedro rocks, and a list of the coral fauna are given.)

1960 The distribution and structural features of recent coral reefs of Jamaica (abs.): Ass'n. of Island Marine laboratories, 3rd Meeting, 1960, pp. 17-18. (Similar in content to 1958a article.)

3. Sediments in atolls, reefs and related areas.

BAARS, D. L.

1963 Petrology of carbonate rocks: Shelf carbonates of the Paradox Basin, A Symposium, Fourth Field Conference 1963; Four Corners Geol. Soc. pp. 101-129. (A discussion of different carbonate

sources and deposits; the chief area mentioned is the Florida Keys. The author concludes that most geologic reefs were mound-like bioherms, rather than actual coral reefs.)

BANKS, J. E.
1959 Limestone conglomerates (Recent and Cretaceous) in southern Florida: Bull. Amer. Assoc. Petroleum Geol., Vol. 43(9): pp. 2237-2242. (Also in Proc. Gulf Coast Assoc. Geol. Soc., 1958,) (Compares the gravel and sand banks in the Florida Keys to the Summit Conglomerate. The gravel-sand banks might be the result of sea-level regression.)

BARDACH, J. E.
1961 Transport of calcareous fragments by reef fishes: Science, Vol. 133 (3446): pp. 98-99. (At least 2300 kilograms of calcareous fragments were ingested and redeposited per hectare in one year. Discussion follows.)

BRAMLETTE, M. N., J. L. FAUGHAN, and R. J. HURLEY
1959 Anomalous sediment deposition on the flank of Eniwetok Atoll: Bull. Geol. Soc. Amer., Vol. 70: pp. 1549-1552. (Short cores penetrated Pliocene deposits with little or no sediment cover. The Tertiary deposits are pelagic; Quaternary deposits are mainly reef debris. Present-day deep currents and the absence of pre-Quaternary tsunamis are given as explanations.)

CAROLL, D.
1957 Beach sands from the northern Marshall Islands (abs.): Soc. Econ. Paleont. and Miner., 31st Ann. Meeting, St. Louis, Program, pp. 55-57. (Largest fragments are coral; smaller ones are coral and shells; the smallest are algae, foraminifera and unidentified fragments. Median grain size is finer and better sorted on the leeward side.)

CLOUD, P. E., Jr.
1962 Environment of calcium carbonate deposition west of Andros Islands, Bahamas: U. S. Geol. Surv. Prof. Paper 350: 138 pp. (About 75% of the calcium carbonate sediment west of Andros results from chemical precipitation. A review of other schools of thought and other workers is quite complete.)

CROZIER, W. J.
1918 The amount of bottom material ingested by Holothurians (Stichopus): Jour. Exp. Zool., Vol. 26(2): pp. 379-389. (Approximately 6 to 7 kilograms of sediment/square meter annually pass through Stichopus' intestines. The chemical and geological alterations, however, do not appear too great.)

DAVIS, J. H.

1940 The ecology and geologic role of mangroves in Florida: Papers Tortugas Lab., Carn. Inst. Wash., Vol. 32: pp. 302-412. (The mangrove community and its ecologic requirements are discussed. Mangroves have been seen to increase the area of the Florida Keys. It is assumed that the mangroves have only been important since the last glacial period.)

FOLK, R. L.

1962 Sorting in some carbonate beaches of Mexico: Trans. N. Y. Acad. Sci., Ser. 2, Vol. 25: pp. 222-244. (Discusses and compares Alacran Reef, Isla del Carmen and Isla Mujeres. Although mean grain size varies greatly, the sorting coefficient remains relatively constant and similar to that of terrigenous beaches.)

FOLK, R. L., M. O. HAYES and R. SHOJI

1962 Carbonate sediments of Isla Mujeres, Quintana Roo, Mexico and vicinity: Guide Book to Field Trip to Peninsula of Yucatan. New Orleans Geol. Soc., Feb. 1-5, 1962. (Sorting on carbonate beaches is similar to terrigenous beaches; rounding varies with wave intensity. The sediment composition of bay, windward and leeward beaches is discussed. Oolite dunes make up most of the island, but ooids are not being formed presently.)

FOLK, R. L. and R. ROBLES

1964 Carbonate sands of Isla Perez, Alacran Reef Complex, Yucatan: Jour. Geol., Vol. 72(3): pp. 255-292. (A rather complete discussion of the sediments and their producers in the littoral zone. Conclusions are similar to those of Folk, 1962 and Folk, et al., 1962.)

FOSBERG, F. R.

1957 Description and occurrence of atoll phosphate rock in Micronesia: Amer. Jour. Sci., Vol. 255: pp. 584-592. (Rock, found in many Micronesian atolls, has a high phosphate content, and resulting apatite crystals. The origin of the phosphate rock is owed to bird guano.)

GAMBINI, A.

1959 Sur la composition de quelques sables coquilliers à Foraminifères des lagons de la Nouvelle-Calédonie: Bull. Soc. Geol. France, Ser. 7(1): pp. 431-434. (Mollusk fragments are the most numerous constituent, followed by Foraminifera. Species of Foraminifera are listed.)

GARMAN, R. K. and H. G. GOODELL

1961 Geochemistry and petrography of the Superior Oil Company test well on Andros Island, B. W. I., as compared to recent Bahaman sediments (abs.): *Geol. Soc. Amer. Spec. Paper*, No. 68: p. 71. (".... the subsurface carbonates closely resemble sediments presently being deposited in the back-reef lagoons, the bights, or on the leeward sides of the present islands of the Bahama platform.")

GEORGE, T. N.
1956 Sedimentary environments of organic reefs: *Sci. Prog.*, Vol. 44: pp. 415-434. (No new data is presented, but this paper is an excellent and concise review of work done on recent and ancient reefs.)

GINSBURG, R. N.
1957 Early diagenesis and lithification of shallow-water carbonate sediments in south Florida: *Regional Aspects of Carbonate Deposition*, Soc. Econ. Paleont. and Miner., Spec. Publ. No. 5: pp. 80-100. (Processes affecting diagenesis and lithification can be divided into three classes: organic, physiochemical and biochemical. These produce recognizable textural, structural and compositional changes. Examples are given.)

GINSBURG, R. N., L. B. ISHAM, S. J. BEIN and J. KUPERBERG
1954 Laminated algal sediments of south Florida and their recognition in the fossil record. Unpublished manuscript. Marine Lab, Univ. Miami, Rept. No. 54-20. 33 pp. (Discusses the various types of algae mats and their physical characteristics, and the different criteria observed in their formation.)

GINSBURG, R. N., R. M. LLOYD, K. W. STOCKMAN and J. S. McCALLUM
1960 Shallow-water carbonate sediments: *Shell Devel. Co. Publ.* No. 246: 31 pp. (Also in Hill, 1963, *The Seas*, Vol. 3: pp. 554-582.) (The constituents of carbonate particles in a sediment tend to show what physical environment produced the sediment. Examples are given.)

GINSBURG, R. N., and H. A. LOWENSTAM
1958 The influence of marine bottom communities on the depositional environment of sediments: *Jour. Geol.*, Vol. 66(3): pp. 310-318. (Certain bottom communities are capable of affecting the physical environments and therefore the sedimentation pattern. Examples given are the blue-green algae, turtle grass baffles, and reefs.)

GOREAU, T. F. and W. D. HARTMAN
1963 Boring sponges as controlling factors in the formation and maintenance of coral reefs; in: *Mechanics of Hard Tissue Destruction*, Publ. 75, Amer. Assoc. Adv. Sci.: pp. 25-54. (Boring sponges mechanically bore into the non-living skeleton of corals. The process is more apparent in deep

water where calcification of the coral is less. Flakes eroded from the coral by the sponges help to form a lime mud in deep water. An extremely interesting discussion of the deep "fore-reef slope" is augmented with photographs.)

GORSLINE, D. L.

1963 Environments of carbonate deposition, Florida Bay and the Florida Straits: Shelf Carbonates of the Paradox Basin, A Symposium, Fourth Field Conference, 1963; Four Corners Geol. Soc.: pp. 130-143. (A review of work in Florida Bay and Florida Straits. The author concludes that most of the material produced on the shelf areas is ultimately transported to the deep sea.)

GRAF, D. L.

1960 Geochemistry of carbonate sediments and sedimentary carbonate rocks: Div. Ill. State Geol. Surv. Circ. 297: Parts I-V. (A review of the literature. Of particular interest is the discussion of beach deposits, reefs and the Bahama platform, in Part I.)

GROSS, M. G.

1964 Variations in the O^{18}/O^{16} and C^{13}/C^{12} ratios of diagenetically altered limestones in the Bermuda Islands: Jour. Geol., Vol. 72(2): pp. 170-194. ("Recent carbonate sediments and major sediment-contributing organisms (except Halimeda) have similar O^{18}/O^{16} and C^{13}/C^{12} ratios which are distinctly different from the O^{18}/O^{16} and C^{13}/C^{12} observed in the stalactites, soil bases and secondary calcites from the limestones. Mechanisms are discussed.)

HAM, W. E. (ed.)

1962 Classification of Carbonate rocks: Amer. Assoc. Petroleum Geol. Mem. 1: 279 pp. (Contains ten papers dealing with content and classification of carbonate rocks. Of particular interest:

Modern concepts of classification of carbonate rocks, by W. C. Ham and L. C. Pray.

Biological, genetic and utilitarian aspects of limestone classification, by D. E. Feray, E. Heuer, and W. G. Hewatt.

Skeletal limestone classification, by H. F. Nelson, W. Brown, and J. H. Brineman.

Classification of modern carbonate sediments, by J. Imbrie and E. G. Purdy.)

HAYES, M. O.

1962 Sedimentology of Desaparecida Bar, Alacran Reef, Mexico (abs.): Texas Jour. Sci., Vol. 14(4): p. 415. (The bar builds up as a result of storm action and is typical of storm-derived sediments. Halimeda and mollusk fragments are the most abundant grains, but large coral blocks are present.)

ILLING, L. S.
1954 Bahaman calcareous sands: Bull. Amer. Assoc. Petroleum Geol., Vol. 38(1): pp. 1-95. (Bahaman oolite sands are considered to be mainly primary in origin, created by physio-chemical processes. The structure and origin of the oolites are discussed in great detail; the relationship between the present-day sediments and oolite rocks is also discussed.)

INGERSON, E.
1962 Problems of the geochemistry of sedimentary carbonate rocks: Geochim. et Cosmochim. Acta, Vol. 26: pp. 815-847. (Problems and significant contributions to the geochemistry of carbonates are discussed. Reefs are included.)

INMAN, D. L., W. R. GAYMAN, and D. C. COX
1963 Littoral sedimentary processes on Kauai, a subtropical high island: Pac. Sci., Vol. 17(1): pp. 106-130. (Beach sediments, composed of terrigenous and biogenic grains, appear to be less well-sorted than continental beaches. Sediment from the fringing reef moves landward and along the beach; between the reefs, sediment appears to move seaward.)

JOHNSON, J. H.
1951 An introduction to the study of organic limestones: Colo. School Mines Quart., Vol. 46(2): 185 pp. (Includes sections concerning coral and algal limestone, both recent and ancient.)

1954a Reefs and the petroleum geologist. Part 2. Reef-building animals; Part 3. Reef-building plants; Part 4. Reef limestones: Mines Mag., Vol. 44: pp. 15-19, 48; 19-20; 20-23; 60-61.*

1954b An introduction to the study of rock-building algae and algal limestones: Colo. School Mines Quart., Vol. 49(2): 117 pp.*

KORNICKER, L. S.
1958 Bahamian limestone crusts: Trans. Gulf Coast Assoc. Soc., Vol. 8: pp. 167-170. (Induration is caused by recrystallization and cementation, probably formed above the intertidal zone. The crusts protect the underlying, less resistant rock from erosion.)

KORNICKER, L. S. and E. G. PURDY
1957 A Bahamian fecal-pellet sediment: Jour. Sed. Pet., Vol. 27: pp. 126-128. (The gastropod Batillaris minima was seen to produce fecal pellets which comprise a major fraction of the sediment in the Bimini area of the Bahamas. Preservation of the pellets is possible.)

KORNICKER, L. S. and D. F. SQUIRES

1962 Floating corals: A possible source of erroneous distribution data: *Limn. and Ocean.*, Vol. 7(4): pp. 447-452. (Some corals are capable of floating; they may float as long as 8 months. This may give considerable error in a sedimentary and ecologic investigation.)

KRAUSS, R. W. and R. A. GALLOWAY

1960 The role of algae in the formation of beach-rock in certain islands of the Caribbean: *Carib. Beach Studies Tech. Rept.* No. 11(E), Coastal Studies Inst., L. S. U., 49 pp. (Algae play no direct role in the formation of beach-rock.)

MacNEIL, F. S.

1954 Organic reefs and banks associated with detrital sediments: *Amer. Jour. Sci.*, Vol. 252: pp. 385-401. (Actual coral reef rock may comprise only a small fraction of the sediment in a coral reef complex. In classifying coral reefs, the author adds the term "table reef".)

McKEE, E. D.

1959 Storm sediments on a Pacific atoll: *Jour. Sed. Pet.*, Vol. 29: pp. 354-364. (Storm deposits include coarse gravel ridges on the reef ridge, new or augmented beach ridges of gravel, gravel sheets on the islands, and sediment in the lagoon which is coarser than usual. Using these characteristics, storm deposits can be recognized in earlier reef deposits.)

McKEE, E. D., J. CHRONIC, and E. B. LEOPOLD

1959 Sedimentary belts in the lagoon of Kapingamarangi Atoll: *Bull. Amer. Assoc. Petroleum Geol.*, Vol. 43(3): pp. 501-562. (Six sedimentary zones are recognized: the coarsest sediments are near shore, the finest in the deepest parts of the lagoon. Comparisons are made with ancient reefs.)

MANNING, R. B. and H. E. KUMPF

1959 Preliminary investigation of the fecal pellets of certain invertebrates of the south Florida area: *Bull. Mar. Sci. Gulf and Carib.*, Vol. 9(3): pp. 291-309. (The fecal pellets of various invertebrates are described and diagrammed.)

MATTHEWS, R. K.

1964 Mineralogy and constituent particle composition of recent carbonate muds of British Honduras (abs.): *Geol. Soc. Amer., Program, 1964 Ann. Meeting*, p. 128. (High-magnesium calcite is primarily Foraminifera debris. High-strontium aragonite content, primarily from coral and *Halimeda* debris, decreases with increasing distance from the shoals.)

Barrier Reef: Jour. Sed. Pet., Vol. 31(2): pp. 215-230. (Close relationships exist between textural variation and physiography and currents. Most sediment is skeletal material; 95% is $CaCO_3$.)

MAXWELL, W. G. H., J. S. JELL, and R. G. McKELLAR
1963 A preliminary note on the mechanical and organic factors influencing carbonate differentiation, Heron Island, Australia: Jour. Sed. Pet., Vol. 33(4): pp. 962-964. (Mechanical, textural and chemical distributions of sediments in the reef area of Heron Island are related to biologic differentiation.)

1964 Differentiation of carbonate sediments in the Heron Island reef: Jour. Sed. Pet., Vol. 34(2): pp. 294-308. (The distribution of sediments is partially related to the stability of the components, which in turn is dependent on whether the components are calcitic or aragonitic. Sedimentary parameters are examined.)

NESTEROFF, W. D.
1956 Le substratum organique dans les dépôts calcaires, sa signification: Bull. Soc. Geol. France, Ser. 6, Vol. 6: pp. 381-390.*

NEUMAN, A. C.
1963 Processes of recent carbonate sedimentation in Harrington Sound, Bermuda: Marine Science Center, Lehigh University, Bethlehem, Penn. 130 pp. (Abstracted in Geol. Soc. Amer., Program, 1964 Ann. Meeting, p. 142.)(Includes bathymetric, hydrographic, ecologic, and geologic studies of the surface sediments. Sediment sources, diagenesis and erosion are discussed.)

NEWELL, N. D., J. IMBRIE and E. G. PURDY
1957 Carbonate facies and biotic communities of northwestern Great Bahama Bank (abs.): Bull. Geol. Soc. Amer., Vol. 68: pp. 1774-1775. (Trade winds have a marked effect on the sediments. Influences of depth and turbulence are seen near the bank margins. Oolites repeatedly exposed to air show a high luster.)

NIINO, H.
1946 An example of reef sediment: Sigenkagaku Kenkyusyo Iho, Vol. 9: pp. 29-35.*

PURDY, E. G.
1961 Bahamian oolite shoals: Geometry of Sandstone Bodies; Amer. Assoc. Petroleum Geol., Spec. Vol., pp. 53-62. (Most shoals of the Great Bahama Bank appear to be drowned aeolian dunes.)

PURDY, E. G. (cont'd)

1963a Recent calcium carbonate facies of the Great Bahama Bank. 1. Petrography and reaction groups: Jour. Geol., Vol. 71(3): pp. 334-335. (Sediment samples were impregnated with a polyester-resin and thin sectioned. By a point-count method, percentages of various constituents could be estimated. Reaction group is defined as a group of sedimentary constituents that will similarly react in a similar environmental condition.)

1963b Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentary facies: Jour. Geol., Vol. 71(4): pp. 472-497. (The distribution of the five sedimentary facies, coralgal, oolitic, grapestone, pellet-mud, and mud facies,is related to local current conditions created by the karst topography.)

PURDY, E. G. and L. S. KORNICKER

1958 Algal disintegration of Bahamian limestone coasts: Jour. Geol., Vol. 66(1): pp. 96-99. (Boring blue-green algae are among the most important agents in the destruction of the coast limestone.)

PUSEY, W.

1963 Recent carbonate shoal complexes in Northern British Honduras (abs.): Bull. Amer. Assoc. Petrol. Geol., Vol. 47(2): p. 367. (Discusses the mud mounds on the shoals in northern British Honduras.)

RANSON, G.

1955 Observations sur des facteurs biologiques de la dissolution du calcaire d'origine récifale dans les Tuamotu: Proc. 8th Pac. Sci. Cong. 3A: pp. 979-988. (Activities of organisms are chiefly responsible for erosion on Tuamotu. Wave erosion is only significant at the reef's edge.)

REVELLE, R. and K. O. EMERY

1957 Chemical erosion of beach rock and exposed reef rock: U. S. Geol. Surv. Prof. Paper 260-T: pp. 699-709. (The marked diurnal changes of the properties of the water probably cause a gradual erosion of the beach rock. Data are given to support the hypothesis.)

REVELLE, R. and R. W. FAIRBRIDGE

1957 Carbonates and carbon dioxide: in Hedgpeth, Treatise on Marine Ecology and Paleoecology: Geol. Soc. Amer. Memoir 67(1): pp. 239-296. (An excellent review of the biogeochemical aspects of carbonate deposition in sea water. Includes a discussion of the different biologic contributors to carbonate detritus.)

RODGERS, J.

1957 The distribution of marine carbonate sediments, a review: *Regional Aspects of Carbonate Deposition*, Soc. Econ. Paleont. and Miner., Spec. Publ. No. 5: pp. 2-14. (Marine carbonate sediments can be divided into deep sea sediments, organic reefs and continental lime muds, and associated limestones. A general discussion follows.)

RUSSELL, R. J.

1959 Caribbean beachrock observations: *Zeit. Geomorph.*, Vol. 3: pp. 227-236.*

1962 Origin of beach rock: *Zeit. Geomorph.*, Vol. 6(1): pp. 1-16. (The cement for beach rock originates in the ground water, not sea water. Beach rock is thickest where seasonal variations in sea level are greatest. Many Caribbean examples are cited.)

RUSSELL, R. J. and W. G. McINTIRE

1965 Southern hemisphere beach rock: *Geog. Review*, Vol. 55(1): pp. 17-45. (The cementation by calcite is in the zone of water-table migration, and is not related to the perculation of sea water. Beach rock is generally only visible on retreating shorelines. Southern hemisphere examples are given.)

SCHLANGER, S. O.

1957 Dolomite growth in coralline algae: *Jour. Sed. Pet.*, Vol. 27(2): pp. 181-186. (Algae were the main dolomitized sedimentary constituents found in the subsurface Eocene limestone on Eniwetok. The magnesium content of the algae is suggested to be insufficient to account for such complete dolomitization.)

SIEGEL, F. R.

1960 The effect of strontium on aragonite-calcite ratios of Pleistocene corals: *Jour. Sed. Pet.*, Vol. 30(2): pp. 297-304. (High Sr content seems to inhibit the aragonite to calcite process.)

STODDART, D. R.

1964 Carbonate sediments of Half Moon Cay, British Honduras: *Atoll Res. Bull.*, No. 104: 16 pp. (A quantitative study of the size distribution of the sediments. Different type sediments are sharply defined by size and shape, which are related to the organic derivation of the sediments.)

STUBBINGS, H. G.

1938 Marine sediments from the islands and reefs of the Great Barrier Reef: *Great Barrier Reef Exped. Sci. Rept.*, Vol. 4(3): pp. 97-104.*

STUBBINGS, H. G. (cont'd)
1939 The marine deposits of the Arabian Sea: *John Murray Exped. Sci. Repts.*, Vol. 3(2): pp. 32-158. (Some coral is found in shallower depths; species are listed.)

TRENCHMANN, C. T.
1951 Note on a Pleistocene coral-rock in Jamaica, altered into material resembling bauxite or laterite: *Quart. Jour. Geol. Soc. London*, Vol. 107: pp. 443-444. (This phenomenon can possibly be explained by washing with sea water or the growth of algae.)

VAN ANDEL, T. H., J. R. CURRAY and J. V. VEEVERS
1961 Recent carbonate sediments of the Sahul Shelf northwestern Australia: *Coastal and Shallow-water Res. Conf., 1961*. pp. 564-567. (Includes a sediment map of the area. Corals are absent on the banks.)

Van OVERBEEK, J. and R. E. CHRIST
1947 The role of a tropical alga in beach sand formation: *Amer. Jour. Bot.*, Vol. 34: pp. 299-300. (*Halimeda* may not only cement, but may also be an important component in some beach rocks.)

WOLF, K. H.
1962 The importance of calcareous algae in limestone genesis and sedimentation: *Nues Jahrbuch Geol. Paleont. Monatshefte*: pp. 245-261. (Reviews the types of algal structures found in limestones and their importance as sedimentary contributors.)

WOOD, E. J. F.
1962 The microbiology of coral reefs: *Proc. 9th Pac. Sci. Cong.*, 1957, Vol. 4: pp. 171-173. (A brief discussion of organic precipitation of calcium carbonate on coral reefs.)

WRIGHT, T. and L. S. KORNICKER
1962 Sand transport of marine shells by birds on Perez Island, Alacran Reef, Campeche Bank, Mexico: *Jour. Geol.*, Vol. 70 (5): pp. 616-618. (The Brown Noddy Tern lines its nest with marine shells (mostly pelecypods) and other debris. This causes an accumulation of shells on the beach which may lead to a misinterpretation of the area.)

II ECOLOGY

1. General Conditions

BLUMENSTOCK, D. I.
1961 A report on typhoon effects upon Jaluit Atoll: Atoll Res. Bull. 75: 105 pp. (Living coral on the reef side was uprooted and deposited on the reef to form offshore bars; there was little erosive action on the coral in the lagoon. The general tone is one of cataclysmic erosion and sedimentation.)

BLUMENSTOCK, D. I., F. R. FOSBERG, and C. G. JOHNSON
1961 The re-survey of the typhoon effects on Jaluit Atoll in the Marshall Islands: Nature Vol. 189: pp. 618-620. (Rubble bar on the reef moved landward. Other effects of the typhoon were modified by normal activity.)

BURKHOLDER, P. R. and L. M. BURKHOLDER
1960 Photosynthesis in some Alcyonacean corals: Amer. Jour. Bot., Vol. 47(10): pp. 866-872. (Also gives oxygen production rates for *Porites porites* and turtle grass, *Thalassia testudinum*.)

FOSBERG, F. R.
1961 Qualitative description of the coral atoll ecosystem: Atoll Res. Bull., No. 81: 11 pp. (Discussion of the general"... physical and 'physiological' framework of the coral atoll ecosystem" and the equilibrium that is achieved.)

GERLACH, S. A.
1961 The tropical coral reef as a biotope: Atoll Res. Bull., No. 80, 6 pp. (The tropical coral reef corresponds to the sublittoral algal region of temperature zones. Different feeding types are more common in dead coral than live coral; this may be related to the mucus that living coral secretes.)

GORDON, M. S. and H. M. KELLY
1962 Primary productivity of an Hawaiian coral reef: a critique of flow respirometry in turbulent waters: Ecology, Vol. 43(3): pp. 473-480. (Points out some of the errors in methods of measuring productivity that have been used by other workers; some corrective insights are offered. A coral reef appears to be non-autotrophic.)

GOREAU, T. F.
1959 The ecology of Jamaican coral reefs. I. Species composition and zonation: Ecology, Vol. 40(1): pp. 67-89. (A listing of species present, and the ecologic zonations. Ecologic factors affecting the reef growth are mentioned. Buttresses may be growth forms, not erosional.)

GOREAU, T. F. (cont'd)

1960 On the physiological ecology of the coral *Meandrina brasiliensis* (Milne-Edwards and Haime) in Jamaica (abs.) *Assoc. of Island Marine Laboratories, 3rd meeting, 1960*, pp. 17-18. (Zooxanthellae produce very little oxygen, and therefore are probably heterotrophic. The great increase in Meandrina's surface area with increased size appears to be an adaptation for life on unstable, muddy substrates.)

1964 Mass expulsion of zooxanthellae from Jamaican reef communities after Hurricane Flora: *Science*, Vol. 145(3630): pp. 383-386. ("It is believed that expulsion of the zooxanthellae was induced by contact with water of lowered osmotic pressure on the surface of the sea, rather than by sedimentation or fouling.")

GOREAU, T. F., V. T. LLAUGER, E. L. MAS, and E. R. SEDA

1960 On the community structure, standing crop and oxygen balance of the lagoon at Cayo Turrumote (abs.): *Ass'n.of Island Marine Laboratories, 3rd Meeting, 1960*, pp. 8-9. (The faunal and floral components of the lagoon community consume about 50 percent more oxygen than they produce. The additional oxygen and food is brought in from the outside.)

GRIPP, K.

1958 Ecologie de quelques Madréporaires de la Mediterranée: *Vie et Milieu*, Vol. 9(4): pp. 379-411. (Deals with solitary corals from deeper waters. Describes different species and the general modes of life, distribution and biotope formation.)

HIATT, R. W.

1957 Factors influencing the distribution of corals on the reef of Arno Atoll, Marshall Islands: *Proc. 8th Pac. Sci. Congr.* 3A: pp. 929-970. (Ecologic zonations of corals are described, and influencing factors are assessed. Due to a lack of variable environmental factors, there is no clear-cut zonation in the lagoon.)

KINSMAN, D. J. J.

1964 Reef coral tolerance of high temperatures and salinities: *Nature*, Vol. 202(4939): pp. 1280-1282. (Temperatures in the Persian Gulf reef tracts vary as much as 10°C diurnally and 20°C annually. Large masses of *Porites* are seen in water having salinities up to 48 o/oo.)

KOHN, A. J.

1961 The biology of atolls: *Bios*, Vol. 32(3): pp. 113-126.*

KOHN, A. J. and P. HELFRICH

1957 Primary organic production of a Hawaiian coral reef: *Limn. and Ocean.*, Vol. 2(3): pp. 241-251. (Productivity was measured

by measuring changes in oxygen content of the water flowing over Kapaa Reef, Kauai. The very high productivity, 2900 grams of organic carbon/meter^2/year, of this reef and other tropical coral reefs is due to photosynthesis by benthic algae on the reef platforms.)

MOTODA, S.
1940 Environment and life of the massive coral Goniastrea aspera Verrill, inhabiting the reef flat in Palao: Palao Trop. Biol. Sta. Studies, Vol. 2(1): pp. 61-104. (Measurements of air and water temperatures, tides, water depth, pH, light intensity, specific gravity of the water, oxygen saturation, oxygen exchange by corals, sediment in the water, and exposure to air. Comparisons are made with the findings of other workers.)

ODUM, H. T., P. R. BURKHOLDER, and J. RIVERO
1959 Measurements of productivity of turtle grass flats, reefs and the Bahia Fosforescente of southern Puerto Rico: Publ. Inst. Marine Sci., Univ. Texas, Port Aransas, Vol. 6: pp. 159-170. (Comparisons are made between reefs and other ecologic environments. Organic production on the reef was high.)

RANSON, G.
1964 Biologie des coraux: III. Rapports des coraux avec leur milieu: Cahiers du Pacif., No. 6: pp. 51-70. (Ecologic relationships of coral with water depth, salinity, light, temperature and currents. A good review of past workers.)

SALVAT, B.
1964 Prospections faunistiques en Nouvelle-Calédonie dans le Cadre de la Mission d'études des récifs coralliens: Cahiers du Pacif., No. 6: pp. 77-120. (Includes ecologic and sedimentologic descriptions of lagoonal areas where biologic collections were made.)

SLACK-SMITH, R. J.
1959 An investigation of coral deaths at Peel Island, Moreton Bay, in early 1956: Univ. Queensland Zool. Papers, Vol. 1(7): pp. 211-222.*

SQUIRES, D. F.
1958 Stony corals from the vicinity of Bimini, Bahamas, British West Indies: Bull. Amer. Mus. Nat. Hist., Vol. 115(4): pp. 219-262. (Coral fauna and ecologic conditions were noted at 15 stations. Faunal assemblages show 2 ecologic zones; bank margin fauna, and bank and lagoon fauna.)

SQUIRES, D. F. (cont'd)

1962 Corals at the mouth of the Rewa River, Viti Levu, Fiji: *Nature*, No. 4839: pp. 361-362. (Coral increased in number and species away from the river, as salinity increased and turbidity decreased.)

STEPHENSON, T. A.

1958 Coral reefs regarded as seashores: *Proc. XVth Intern. Congr. Zool.*, pp. 244-246. (..."a coral reef is a growth which replaces, in the tropics, certain other low-level growths characteristic of colder regions.")

STEPHENSON, T. A. and A. STEPHENSON

1950 Life between tide marks in North America. I. The Florida Keys: *Jour. Ecol.*, Vol. 38: pp. 354-402. (Ecologic distributions discussed are mainly confined to intertidal flora and fauna.)

STEPHENSON, W. R. E., R. ENDEAN, and I. BENNET

1958 An ecological survey of the marine fauna of Low Isles, Queensland: *Australian Jour. Marine and Freshwater Res.*, Vol. 9 (2): pp. 261-318. (Effects of a cyclone on the reef. General ecology investigated; death of corals owed to heavy swell and sediment. Massive corals are cyclone-resistant; branching corals are not.)

STODDART, D. R.

1962 A short account on catastrophic storm effects on the British Honduras reefs and cays: *Nature*, Vol. 196(4854): pp. 512-515. (Up to 80% of the reef coral was destroyed in the area of the storm center.)

1963 Effects of hurricane Hattie on the British Honduras reefs and cays, October 30-31, 1961: *Atoll Res. Bull.*, No. 95: 142 pp. (The effects on the reefs were most disasterous in those areas exposed to the full force of the hurricane. Most affected was the slender branching coral *Acropora cervicornis*; least affected were the massive heads of *Monastrea annularis*. Most of the cays were partially eroded; some of the smaller ones had vanished after the storm.)

STORR, J. F.

1955 Ecology and oceanography of the coral-reef tract, Abaco Island, Bahamas. *Geol. Soc. Amer. Spec. Paper* 79: 98 pp. (abs. in *Dissertation Abs.*, Vol. 16(2): p. 412.) (Ecologic transects of the Abaco coral reefs. Coral growth and structures are related to different ecologic factors, including waves, light, currents, etc. Many quantitative measurements are given, including population counts.)

TANDY, G. and J. COLMAN
1931 Superficial structure of coral reefs. Animal and plant successions on prepared substrata: *Carn. Inst. Wash. Year Book*, Vol. 30: pp. 395-396.*

VERMEER, D. E.
1963 Effects of hurricane Hattie, 1961, on the cays of British Honduras: *Zeit. Geomorph.*, Vol. 7(4): pp. 332-354. (The waxing phase of the hurricane was destructive; the wanning phase was dominantly reconstructuve. The unstable sand bores were often completely washed away; no stable cay was completely removed.)

VOSS, G. L. and N. A. VOSS
1955 An ecological survey of Soldier Key, Biscayne Bay, Florida: *Bull. Mar. Sci. Gulf and Carib.*, Vol. 5(3): pp. 203-229. (*Porites*, the only common coral, is found only east of Soldier Key, where sedimentation is slight enough to allow a minimal growth.)

WHITFIELD, R. P.
1901 Notice of a remarkable case of combination between two different genera of living corals: *Bull. Amer. Mus. Nat. Hist.*, Vol. 14 (17): pp. 221-222. (*Ctenophyllia sp*. was found growing in the middle of a massive specimen of *Meandrina labyrinthica*.)

YONGE, C. M.
1958 Ecology and physiology of reef-building corals; in Buzzati-Traverso, *Perspectives in Marine Biology*: Univ. Calif. Press, Berkeley. pp. 117-135. (A good review of past literature and suggestions for future investigations of reef ecology and the biology of the coral.)

2. Communities (with emphasis on organisms other than corals)

ABBOTT, I. A.
1961 A check list of marine algae from Ifaluk Atoll, Caroline Islands: *Atoll Res. Bull.*, No. 77: 5 pp. (85 species; relative abundances are given.)

BARDACH, J. E.
1959 The summer standing crop of fish on a shallow Bermuda Reef: *Limn. and Ocean.*, Vol. 4(1): pp. 77-85. (490 kilograms of fish per hectare, estimated by visual count.)

BONHAM, K. and E. E. HELD

1963 Ecological observations on the sea cucumbers *Holothuria atra* and *H. leucospilota* at Rongelap Atoll: *Pac. Sci.*, Vol. 17(3): pp. 305-314. (The ecology of the animals is discussed. It is estimated that the *Holothuria* population, of 5×10^6 individuals, ingests and egests 2×10^8 kg. of sand yearly.)

CUSHMAN, J. A., R. TODD and R. J. POST

1954 Recent Foraminifera of the Marshall Islands: *U.S. Geol. Surv. Prof. Paper* 260-H: pp. 319-384. (331 species and varieties are listed; ecologic distribution and abundances are given. Depth and access to the open ocean seem to be the limiting factors affecting distribution.)

DANIEL, C.

1949 Encrusting Foraminifera of Krusadi Island: *Jour. Madras Univ.*, 18(B): pp. 27-37.*

DAWSON, E. Y.

1955 An annotated list of marine algae from Eniwetok Atoll, Marshall Islands: *Pac. Sci.*, Vol. 11(1): pp. 92-132. (Includes a key to the genera.)

1956 Some algae from Canton Atoll: *Atoll Res. Bull.*, No. 65: 6 pp. (A list of the species and ecologic distribution.)

1961 The rim of the reef. Calcareous algae occupy a major role in the growth of atolls: *Nat. Hist.*, Vol. 70(6): pp. 8-17.*

DOTY, M. S.

1957 An enumeration of the hypothetical roles of algae in coral atolls: *Proc. 8th Pac. Sci. Congr.* 3A: pp. 923-928. (Coralline algae absorb the nutrient salts that are used in the atoll complex. Algae also are the major decomposers and sediment formers.)

1962 Functions of the algae in the central Pacific: *Proc. 9th Pac. Sci. Cong.*, 1957, Vol. 4: pp. 148-155. (The roles of algae in productivity, and "construction and destruction of shores, islands, and reefs" are reviewed.)

GOHAR, H. A. F. and G. N. SOLIMAN

1963a On three mytilid species boring in living corals: *Publ. Mar. Biol. Sta. Al-Ghardaqa (Red Sea)*, No. 12: pp. 65-98. (Different species of boring mollusks appear to bore in different species of coral. The mechanism of boring is discussed.)

GOHAR, H. A. F. and G. N. SOLIMAN (cont'd)

1963b On the biology of three Coralliophilids boring in living coral: *Publ. Mar. Biol. Sta. Al-Ghardaqa (Red Sea)*, No. 12: pp. 99-126. (The general taxonomy, biology and boring mechanism are discussed.)

1963c On the rock-boring lamellibranch *Rocellaria ruppelli* (Deshayes): *Publ. Mar. Biol. Sta. Al-Ghardaqa (Red Sea)*, No. 12: pp. 145-158. (The general taxonomy, biology and boring mechanism are discussed.)

1963d On two mytilids boring in dead coral: *Publ. Mar. Biol. Sta. Al-Ghardaqa (Red Sea)*, No. 12: pp. 205-218. (The general taxonomy, biology and boring mechanisms are discussed.)

HARTMAN, O.

1954 Marine Annelids from the northern Marshall Islands: *U. S. Geol. Surv. Prof. Paper* 260-Q: pp. 619-644. (Over 100 species of marine annelids are identified, including some that are destructive to coral.)

HIATT, R. W. and D. W. STRASBURG

1960 Ecological relationships of the fish fauna on coral reefs of the Marshall Islands: *Ecol. Monog.*, Vol. 30(1): pp. 65-127. (The feeding habits of 233 species of reef fish are described. A surprisingly large number ingest coral polyps. Some relationships of the fish to their habitat are also considered.)

JOHNSON, M. W.

1954 Plankton of Northern Marshall Islands: *U. S. Geol. Surv. Prof. Paper* 260-F: pp. 301-314. (The plankton fauna are characterized by some species which are endemic to the lagoon. Plankton in the lagoon are about four times more abundant than in the windward portion of the reef, and twice as concentrated as the leeward areas. Vertical and diurnal distributions are also discussed.)

MARSDEN, J. R.

1962 A coral-eating Polychaete: *Nature*, Vol. 193: p. 598. (*Hermodice carunculata* was observed on ten occasions to eat portions of the coral *Porites porites*. Nematocysts were found in the worms' fecal pellets.)

MARSHALL, S. M.

1933 The production of microplankton in the Great Barrier Reef region: *Great Barrier Reef Exped. Sci. Rept.*, Vol. 2(5): pp. 111-157. (Diatoms dominate and are more abundant on the reef than in the open ocean. Abundance varies with the season.)

MOUL, E. T.

1957 Preliminary report on the flora on Onotoa Atoll, Gilbert Islands: Atoll Res. Bull., No. 57: 48 pp. (The taxonomy and the distribution of the marine algae are discussed.)

1964 New records of *Halimeda* and *Udotea* for the Pacific area: Atoll Res. Bull., No. 106: 10 pp.

PALUMBO, R. F.

1962 The relationships between atolls and benthic algae: Proc. 9th Pac. Sci. Cong., 1957, Vol. 4: pp. 168-170. (The occurrence of algae in the atoll system is dependent upon the physical and chemical factors of the water, the form of the alga, and the "biologic factors imposed by the other organisms in the vicinity.")

RUSSELL, F. S. and J. S. COLMAN

1934 The composition of the zooplankton of the barrier reef lagoon: Great Barrier Reef Exped. Sci. Rept., Vol. 2(6): pp. 159-175. (Mainly descriptive; based on vertical hauls.)

SPRINGER, V. G. and A. J. McERLEAN

1962 A study of the behavior of some tagged South Florida coral reef fishes: Amer. Mid. Nat., Vol. 67(2): pp. 386-397. (Several larger species of reef fish may occupy quasi-permanent homes on the reef.)

TSUDA, R. T.

1964 Floristic report on the marine algae of selected islands in the Gilbert group: Atoll Res. Bull., No. 105: 13 pp.

WOOLACOTT, L.

1955 Coral dwellers: Proc. Roy. Zool. Soc. New South Wales, Vol. 54: pp. 79-81.*

YONGE, C. M.

1963 Rock-boring organisms: in Mechanisms of Hard Tissue Destruction, Amer. Assoc. Adv. Sci., Publ. 75, pp. 1-24. (Deals with the nutrition and the mode of life of boring organisms. Although most of the phyla are covered, the bulk of the discussion concerns rock-boring bivalves.)

ZULLO, V. A.

1961 A new subgenus and species of coral-inhabiting barnacle from the Gulf of California: Veliger, Vol. 4(2): pp. 71-75.

3. Oceanographic and meteorologic conditions on or near coral reefs

BERTHOIS, L., *et al.*
1963 Le renouvellement des eaux du lagon dans l'atoll de Maupihaa-Mopelia (Iles de la Société): *C.R. Acad. Sci. Paris*, 257: pp. 3992-3995.*

BLUMENSTOCK, D. I. and D. F. REX
1960 Microclimatic observations at Eniwetok: *Atoll Res. Bull., No. 71*: 158 pp. (A year's meteorologic study, including ocean and lagoon water temperatures. Also includes a general description of the topography of several of the islands in the area.)

BODEN, B. P. and E. M. KAMPA
1953 Winter cascading from an oceanic island and its biologic implications: *Nature*, Vol. 171: pp. 426-427. (Studies were made in Bermuda. Winter circulation is cyclonic; in the summer there is less vertical motion. The latter allows for better conditions for endemic plankton.)

BURNSIDE, R. J.
1957 Surf-strength factors in reef growth and development (abs.): *Soc. Econ. Paleont. and Miner., 31st Ann. Meeting*, St. Louis, Program, p. 54.*

FORD, W. L.
1949 Radiological and salinity relationships in the water at Bikini Atoll: *Trans. Amer. Geophys. Union* 30(1): pp. 49-54. (Gives some hydrographic measurements; proposes circulation studies using radioactivity as a tracer.)

FOSBERG, F. R.
1957 Slicks on ocean surface downwind from coral reefs: *Atoll Res. Bull.* 53: 4 pp. (Among the explanations given for slicks, is that the reef might frequently emit an oil substance.)

GALTSOFF, P. S.
1933 Pearl and Hermes Reef, Hawaii. Hydrographical and biological observations: *Bull. B. P. Bishop Mus.* No. 107: 49 pp(Discussion of fauna, salinity, water temperatures and tides).

JOHNSON, M. W.
1949 Zooplankton as an index of water exchange between Bikini Lagoon and the open sea: *Trans. Amer. Geophys. Union* 30(2): pp. 238-244. (Highest plankton concentrations are in the lagoon; lowest concentrations are on the seaward side. The lagoonal circulation is shown to be semi-closed.)

JONES, J. A.

1963 Ecological studies of the southeastern Florida patch reefs. Part I. Diurnal and seasonal changes in the environment: *Bull. Mar. Sci. Gulf and Caribbean*, Vol. 13(2): pp. 282-307. (Diurnal and seasonal changes in the physical and chemical characteristics of the water on a patch reef were measured by taking oceanographic stations during 4 different periods of the year, each station lasting about 3 days. Results are discussed.)

LAVOIE, R. L.

1963 Some aspects of the meteorology of the tropical Pacific viewed from an atoll: *Atoll Res. Bull.*, No. 96: 80 pp. (Observations made on Eniwetok Atoll. Diurnal meteorologic variations are discussed with the use of a large amount of data.)

McCLENDON, J. F.

1918 On the changes in the sea and their relation to organisms: *Papers Tortugas Lab*, Carn. Inst. Wash., Vol. 12: pp. 213-259. (Includes diurnal variations in oxygen in the Florida Keys reefs.)

MAO, H. and K. YOSHIDA

1955 Physical oceanography in the Marshall Islands Area: *U. S. Geol. Surv. Prof. Paper* 260-R: pp. 645-684. (Includes flow patterns computed from dynamic anomalies, directly measured currents, temperature-salinity relationships, and some general remarks on oxygen distribution. Particular emphasis is placed on the areas of large eddies between the North Equatorial Current and the Equatorial Counter Current.)

MATSUYA, Z.

1937 Some hydrographical studies of the water of Iwayama Bay in the South Sea Islands: *Palao Trop. Biol. Sta. Studies*, Vol. 1: pp. 95-135. (Includes pH, chlorinity, temperature, oxygen, and alkalinity. Diurnal and monthly variations seem to affect the plankton. The growth of corals is more directly related to the abundance of plankton, currents and waves, than to the hydrographic conditions.)

MUNK, W. H., G. C. EWING, and R. R. REVELLE

1949 Diffusion in Bikini Lagoon: *Trans. Amer. Geophys. Union*, Vol. 30(1): pp. 59-66. (The coefficients of vertical and horizontal diffusion are calculated. Methods, observations and results are given.)

NORTHROP, J.
1962 Geophysical observations on Christmas Island: *Atoll Res. Bull.*, No. 89: 2 pp. (A marked temperature gradient in a shallow lagoon is explained by the constant inflow of fresh water.)

ROBINSON, M. K.
1954 Sea temperature in the Marshall Islands area: *U. S. Geol. Surv. Prof. Paper* 260-D: pp. 281-291. (Annual variations in the vertical and horizontal isotherms are given. These variations seem to indicate seasonal changes in the current patterns of the area.)

SEWELL, R. B. S.
1935 Geographic, oceanographic research in Indian Waters. Part 8. Studies on coral formation in Indian waters: *Asiatic Soc. Bengal Mem.*, Vol. 9(8): pp. 461-540.*

TRACEY, J. I., Jr.
1961 Relations of reefs to water circulation: *Soc. Econ. Paleont. and Miner. Sympos.*, Denver.*

VON ARX, W. S.
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1963 Bibliographie récente relative à l'océanographie physique dans le Pacifique: *Cahiers Pacif.*, No. 5: pp. 127-142. (A rather complete bibliography of recent publications on the physical oceanography in the tropical Pacific.)

III. CORAL - THE ANIMAL

1. Taxonomy of Madreporaria

ALMY, C. C., Jr. and C. C. TORRES
1963 Shallow water stony corals of Puerto Rico: *Caribb. Jour. Sci.* Vol. 3(3): pp. 133-162. (Thirty-eight species of shallow-water stony corals are described. The reefs in the collecting areas, along with environmental studies, are discussed.)

BOSCHMA, H.
1959 The species problem in corals: *Proc. Intern. Congr. Zool. 1958*, pp. 246-248. (Gives specific examples.)

DURHAM, J. W.
1962 Scientific results of the Galapagos Expedition 1953-54 of the International Institute for Submarine Research; Corals from the Galapagos and Cocos Islands: *Proc. Calif. Acad. Sci.*, Vol. 32(2): pp. 41-56. (Species are compared to those of the east Pacific coast and the Indo-Pacific Ocean.)

NEMENZO, F.
1955 Systematic studies on Philippine shallow water Scleractinians: I. Suborder Fungiida: *Nat. Appl. Sci. Bull.*, Vol. 15: pp. 1-84.*

PURCHON, R. D.
1956 A list of corals collected in the vicinity of Singapore: *Proc. Linn. Soc. New S. Wales*, Vol. 79: pp. 90-94.*

RALPH, P. M. and D. F. SQUIRES
1962 The extant scleractinian corals of New Zealand: *Zool. Publ. Victoria Univ., Wellington*, No. 29: pp. 1-19. (There have been no hermatypic corals in New Zealand since the Miocene; present fauna distributions are poorly known.)

SMITH, F. G. W.
1954 Gulf of Mexico Madreporaria: *U. S. Fish. Bull.*, Vol. 55(89): pp. 291-295. (Includes a chart showing location of coral reefs and scattered coral heads in the Gulf of Mexico. The fauna is typically West Indian; species lists are given for both hermatypic and ahermatypic corals.)

SQUIRES, D. F.
1959 Deep-sea corals collected by the Lamont Geological Observatory. I. Atlantic corals: *Amer. Mus. Novitates*, No. 1965, 42 pp. (The corals presented are ahermatypic. Included are photographs of corals, both in prepared specimens and *in situ*, and measurements of the corals' dimensions.)

STEPHENSON, W. and J. W. WELLS

1956 The corals of Low Isles, Queensland. August, 1954: Dept. Zool., *Univ. Queensland Papers*, Vol. 1(4): 59 pp. (A resurvey of the area, and a comparison to the survey made in 1928-29. Cyclones do not seem to greatly affect the abundance of corals.)

THIEL, M. E.

1941 1. Madreporaria: *Résultats Scientifiques des Croisieers du Navire Ecole Belge "Mercator"*. Vol. 3: 28 pp. (Written in German; contains excellent plates of *Porites porites*, *P. astreoides*, *Occulina*, *Lophohelia* and *Astrangia*.)

TUTTON, A. K.

1952 Notes on some little-known corals from N. W. and S. Australia: *Ann. Mag. Nat. Hist*. Vol. 5(12): pp. 975-979. (Includes plates of the genera *Plesiastrea* and *Culicia*.)

UTINOMI, H.

1956 Invertebrate fauna of the intertidal zone of the Tokara Islands. XIV. Stony corals and hydrocorals: *Publ. Seto Marine Biol. Lab.* Vol. 5: pp. 339-346. (Corals are very meager in this area; only 15 species were identified.)

VERRILL, A. E.

1899-1900. Additions to the Anthozoa and Hydrozoa of the Bermudas: *Trans. Conn. Acad. Arts and Sci.*, Vol. X: pp. 551-567. (*Acropora*, *Manicina*, *Agaricia agaricites*, and other common West Indian species are notably absent in Bermuda. *Montastrea annularis* and five additional species are listed and discussed.)

WELLS, J. W.

1955 Recent and subfossil corals of Moreton Bay, Queensland: *Paper Dept. Geol. Univ. Queensland N. S.*, Vol. 4: pp. 4-23.*

1959 Notes on Indo-Pacific Scleractinian corals. Part I. *Oryzotrochus*, a new genus of Turbinolian coral. Part II. A new species of *Turbinaria* from the Great Barrier Reef: *Pac. Sci.*, Vol. 13(3): pp. 286-290.

1961 Notes on Indo-Pacific Scleractinian corals. Part III. A new reef coral from New Caledonia: *Pac. Sci.*, Vol. 15(2): pp. 189-191.

1962 Two new scleractinian corals from Australia: *Rec. Australian Mus.*, Vol. 25(1): pp. 239-241.

2. Biology of Corals

A. Physiology

GOREAU, T. F.

1953 Phosphomonoesterases in reef-building corals: Proc. Nat. Acad. Sci., Vol. 39: pp. 1291-1295. (The high pH optimum, generally over 10, is considered as a possible advantage in rapid and efficient deposition of calcium carbonate.)

1957 Calcification in reef corals: Rept. on Inter-Island Marine Biol., Univ. Puerto Rico, p. 15. (Abstract of previous and later publications)

1958 Calcification and growth in reef-forming corals: Proc. XVth Intern. Congr. Zool., pp. 248-250. (A short paper citing the studies made on coral using a radioactive tracer, Ca^{45}; a discussion follows.)

1959 The physiology of skeleton formation in corals. I. A Method for measuring the rate of calcium deposition by corals under different conditions: Biol. Bull., Vol. 116(1): pp. 59-75. (Calcium uptake increases with increasing temperature, time exposed, and light intensity. An excellent bibliography is included.)

1961 On the relation of calcification to primary productivity in reef building organisms; in The Biology of Hydra: Univ. Miami Press, pp. 269-285. (A summary of work done on the calcium and carbonate uptake of coral and algae. A discussion follows.)

1963 Calcium carbonate deposition by coralline algae and corals in relation to their roles as reef builders: Ann. N. Y. Acad. Sci., Vol. 109(1): pp. 127-167. (Corals appear to be much more dependent on light for calcium carbonate deposition than do algae. Methods for Ca^{45} and C^{14} analyses to determine calcium carbonate deposition and photosynthesis are given.)

GOREAU, T. F. and V. T. BOWEN

1955 Calcium uptake by a coral: Science, Vol. 122(3181): pp. 1188-1189. (Coral reaches equilibrium with the calcium in the surrounding water very quickly. Experiments done with radioactive calcium.)

GOREAU, T. F. and N. I. GOREAU

1959 The physiology of skeleton formation in corals. II. Calcium deposition by hermatypic corals under various conditions in the reef: Biol. Bull., Vol. 117: pp. 239-250. (Growth rates differ with species, individuals, ages, and parts of the same colony.)

GOREAU, T. F. and N. I. GOREAU (cont'd)

1960a The physiology of skeleton formation in corals. III. Calcification rate as a function of colony weight and total nitrogen content in the reef coral *Manicina areolata* (Linnaeus): *Biol. Bull.*, Vol. 118(3): pp. 419-429. (The relation of surface area to volume is relatively constant; this is caused by the folding of the surface as the coral grows. This may allow the coral to remove excess sand faster and also right itself. Calcification rates decrease markedly from the young coral to the adult. Zooxanthellae seem to affect the calcification rate.)

1960b The physiology of skeleton formation in corals. IV. On isotopic equilibrium exchange of calcium between corallum and environment in living and dead reef-building corals: *Biol. Bull.*, Vol. 119(3): pp. 416-427. (Dead corals have a much higher exchange rate of calcium than living corals. This can be explained partly by the "calcium-proof" living coenosac and partly because the living coral is continually growing and thus adding layers of calcium.)

1960c Distribution of labelled carbon in reef-building corals with and without zooxanthellae: *Science*, Vol. 131(3401): pp. 668-669. (Includes light-dark experiments which delineate the use of zooxanthellae in the coral.)

HAND, C.

1956 Are corals really herbivorous?: *Ecology*, Vol. 37: pp. 384-385. (A critical look at Odum and Odum's 1955 *Ecol. Monog.* article which had stated that corals were herbivorous. It appears doubtful that they are. Odum and Odum's reply follows; corals may assimilate diffusable products of the algae.)

HARRISS, R. C. and C. C. ALMY

1964 A preliminary investigation into the incorporation and distribution of minor elements in the skeletal material of scleractinian corals: *Bull. Mar. Sci. Gulf and Caribb.* Vol. 14(3): pp. 418-423. (Concentrations of magnesium and probably other elements seem to vary with different genera. The distribution of any one element within a coral colony is heterogeneous.)

KAWAGUTI, S.

1944 On the physiology of reef corals. VII. Zooxanthella of the reef corals is *Gymnodinium* sp., Dinoflagellate; its culture in vitro: *Palao Trop. Biol. Sta. Studies*: Vol. 2(4): pp. 675-679. (Zooxanthellae, identified as a dinoflagellate *Gymnodinium* sp., are able to be separated from their host and remain alive in culture in vitro.)

KAWAGUTI, S. (cont'd)

1954 Effects of light and ammonium on the expansion of polyps in the coral reefs: *Biol. Jour. Okayama Univ.*, Vol. 2: pp. 45-50. (Day-expanding corals tend to have zooxanthellae on their tentacles; night-expanding corals do not. Day-expanding corals usually have soft skeletons; night-expanding corals have hard skeletons.)

McLAUGHLIN, J. J. A. and P. A. ZAHL

1957 Studies in marine biology. II. In vitro culture of zooxanthellae: *Proc. Soc. Exp. Biol.*, Vol. 95: pp. 115-120. (Isolated zooxanthellae gave rise to forms that were recognized as dinoflagellates. Isolation and nutrition procedures are described.)

1959 Axenic zooxanthellae from various invertebrate hosts: *Ann. N. Y. Acad. Sci.*, Vol. 77: pp. 55-72.*

MARGALEF, R.

1959 Assimilatory pigments from colonial coelenterates of the coral reefs and their ecological meaning: *Invest. Pesquera*, Vol. 15: pp. 81-101. (Assimilatory pigments from zooxanthellae may be useful ecologic and physiological indicators.)

RANSON, G.

1961 Biologie des Coraux: *Cahiers Pacif.*, No. 3: pp. 75-94. (Mainly concerns the interrelationships between coral and zooxanthellae, but does discuss the feeding methods of coral. The utilization of the coral's waste products by the zooxanthellae constitutes their primary contribution to the coral.)

STEPHENS, G. C.

1960 Uptake of glucose from solution by the solitary coral *Fungia*: *Science*, Vol. 131(3412): p. 1532. (Uptake is sufficient to maintain the coral's metabolism.)

1962 Uptake of organic material by aquatic invertebrates. 1. Uptake of glucose by the solitary coral *Fungia* *scutaria*: Biol. Bull., Vol. 123(3): pp. 648-659. (Uptake rate is dependent upon light intensity.)

THORPE, J. E. and P. K. BREGAZZI

1960 Experimentations and observations on the corals at Rendezvous Cay: *Gen. Rept. Camb. Exped. to Brit. Honduras, 1959-1960*, pp. 22-28.*

WAINWRIGHT, S. A.

1963 Skeletal organization in the coral *Pocillopora* *damicornis*: *Quart. Jour. Microscop. Sci.*, Vol. 104(2): pp. 169-184. (At least 99.9% of the skeleton is aragonite; the organic component being from 0.01 to 0.1%. The process of skeletal formation is discussed.)

1964 Studies of the mineral phase of coral skeleton (hermatypic Pocillopora damicornis, ahermatypic Lophelia pertusa): Exp. Cell Res., Vol. 34(2): pp. 213-230.*

YONGE, C. M.

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ZAHL, P. A. and McLAUGHLIN, J. J. A.

1957 Isolation and cultivation of Zooxanthellae: Nature, Vol. 180: pp. 199-200. (Motile phases indicate zooxanthellae to be dinoflagellates. Methods of study are given.)

1959 Studies in marine biology. IV. On the role of algal cells in the tissues of marine invertebrates: Jour. Protozool., Vol. 6: pp. 344-352.*

2. B. Reproduction and embryology

DAWADOFF, C.

1951 Evolution des ébauches blastiques chez l'embryon de quelques Madreporaires: C. R. Acad. Sci. Paris, 232: pp. 780-783.*

HAWES, F. B.

1958 Preliminary observations on the settlement of the Actinula larva of the Tubularia larynx: Ann. Mag. Nat. Hist., pp. 147-155. (Light affects the settlement more than temperature, but no indication that the larva is capable of selecting a place for settlement.)

KAWAKAMI, I.

1941 Asexual reproduction in some reef corals: Palao Trop. Biol. Sta. Studies 2(2): 147-156. (Discusses both intra- and extra-tentacular budding.)

YONGE, C. M.

1958 Some genetical problems presented by sessile Coelenterates: in Buzzati-Traverso, Perspectives in Marine Biology: Univ. Calif. Press, Berkeley. pp. 609-611. (Experiments on planulae are proposed to help differentiate between species and growth form.)

2. C. Growth rate and colony formation

GOREAU, T. F.

1961 Problems of growth and calcium deposition in reef corals: *Endeavour*, 20(77): pp. 32-39. (Zooxanthellae play a very important role in skeletogenesis, but not in the actual nutrition of the coral. Possible calcification processes are shown.)

MA, T. Y. H.

1957 The effects of warm and cold currents in the Southwestern Pacific on the growth rate of reef corals: *Oceanographica Sinica*, Vol. 5(1): 34 pp. (The cold current along the China coast both narrows the distribution of the corals and affects their annular growth rate.)

1959 Effect of water temperatures on growth rate of reef corals: *Oceanographica Sinica Spec. Vol. 1*: 116 pp.*

MAVOR, J. W.

1915 On the development of the coral *Agaricia fragilis* Dana: *Proc. Amer. Acad. Arts and Sci.* Vol. 51(9).*

SQUIRES, D. F.

1960 Scleractinian corals from the Norfolk Island cable: *Rec. Aukland Inst. and Mus.* 5(3/4): pp. 195-201.*

WELLS, J. W.

1963 Coral growth and geochrometry: *Nature*, Vol. 197 (4871): pp. 948-950. (Diurnal growth lines and annual growth increments can be used to approximate the number of days of the year in the geologic past. A further discussion can be found in Runcorn, 1964, *Nature*, Vol. 204: pp. 823-825.)

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1958 Selected bibliography on the geology or organic reefs: Reef Terminology Index Project, Circular No. 3. 51 pp.

BAYER, F. M.
1957 Recent Octocorals: in Treatise on Marine Ecology, Geol. Soc. Amer. Mem. 67: pp. 1105-1107. (A basic source for references dealing with Alcyonarians.)

BURKE, H. W.
1951 Contributions by the Japanese to the study of coral reefs; (Unpublished): U. S. Geol. Surv., Military Branch, Washington, D. C. (Includes abstracts of various Japanese papers, and interviews with some of the more well-known workers.)

DAVIS, W. M.
1928 The coral reef problem: Amer. Geog. Soc. Spec. Publ. No. 9: 596 pp. (One of the classic works on coral reefs: includes over 700 references, all prior to 1928.)

FOSTER, H. L.
1956 Annotated bibliography of geologic and soils literature of western north Pacific islands: U. S. Army, Chief Eng., Intelligence Div., Headqtrs. U.S. Army Forces Far East (Tokyo): 897 pp.*

GRAF, D. L.
1960 Geochemistry of carbonate sediments and sedimentary carbonate rocks. Part IV-B. Bibliography: Div. Ill. State Geol. Surv. Circ. 309, Urbana, Ill., 55 pp.

MOORE, R. C.
1956 Treatise on Invertebrate Paleontology. F. Coelenterata: Geol. Soc. Amer. and Univ. Kansas Press, Lawrence, Kansas.

PUGH, W. E. (ed.)
1950 Bibliography of organic reefs, bioherms and biostromes. Seismic Serv. Corp., Tulsa, Okla. 139 pp. (Contains over 1000 references, including many concerned with ancient reefs.)

RANSON, G.
1958 Coraux et recifs coralliens (Bibliographie): Bull. Inst. Monaco, No. 1121: 80 pp.

SACHET, M.-H. and F. R. FOSBERG
1955 Island bibliographies: Nat. Acad. Sci.- Nat. Res. Council Publ. 335: 577 pp.*

SANDERS, J. E.

1960 Bibliographie des Travaux recents de sedimentologie. Carbonate Rocks: *Symposium: Sedimentology and the Oil Industry*; Fifth World Petroleum Congress, New York, 1959. pp. 88-109. (Primarily interested in carbonate sedimentation, papers published from 1952 to 1959 are included.)

WELLS, J. W.

1957a Annotated bibliography - Corals; in Hedgpeth, *Treatise on Marine Ecology*, Geol. Soc. Amer. Mem. 67(1): pp. 1089-1104. (Emphasizes the major works dealing with the biology and ecology of coral reefs. About 300 references are annotated; most all also appear in Ranson, 1958.)

1957b Annotated bibliography - Corals; in Ladd, *Treatise on Paleoecology*, Geol. Soc. Amer. Mem. 67(2): 773-782.

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ATOLL RESEARCH BULLETIN

No. 112

Atoll News and Comment

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ATOLL NEWS AND COMMENT

We are very pleased with the response to previous News and Comment numbers of ARB, and with the abundance of items sent in as news, and have included most of them below. We expect to continue this feature as long as readers are enough interested to provide material. Material supplied as signed items will be included in that form or as summary paragraphs by the editors if that seems indicated. Naturally preferred are items that can be used without change or editing.

It will be noticed that many of the items referred to in the sections below are in the form of duplicated reports of very limited distribution, either because they were prepared for special purposes, or because the sponsors had made no provision for adequate publication. This seems a great pity when serious work and professional time have been expended, and when interest in information about islands is strong. We would like to draw attention to the fact that the pages of the ARB are open to such material, regardless of its source, so long as the information seems sound and of scientific importance and the manuscripts are carefully written and typed. The ARB exists for the purpose of placing information on atolls and reefs in the hands of those who need it without delay.

Current Investigations

Central Pacific Ocean Area:

Under the auspices of the Pacific Ocean Biological Survey Program of the Division of Birds, Smithsonian Institution (see ARB 108) Dr. C. H. Lamoureux, of the University of Hawaii, and Mr. C. R. Long, of the Smithsonian, are assembling comprehensive collections of plants from the Line Islands, Phoenix Islands, Hawaiian Atolls, and to a lesser extent from the Gilberts, Marshalls, and Wake. Many of these have been collected by the above-mentioned investigators, others by the various ornithologists involved with the other aspects of the program. When this study is completed we should have an excellent knowledge of the flora of these atolls and the detailed distribution and occurrence of the species. Monographic reports are being prepared for various atolls, which should include consideration of the flora as well as the fauna and general ecology. It is hoped that the sponsors of this program will allow these reports to be made generally available as soon as they are ready.

Eniwetok:

Mr. Ernst S. Reese writes (Nov. 22, 1964) that he visited the Eniwetok Laboratory last June where he studied the ecology and behavior of the coconut crab, Birgus latro. He says "perhaps the most fascinating thing was the successful rearing of the young from the eggs. Studying the phase where they emerge from the sea to take up their terrestrial life was most fascinating. The young very definitely live in shells, reflecting very nicely their hermit crab ancestry."

Tokelau Islands:

Dr. Marshall Laird, of the Institute of Parasitology, McGill University, has kindly sent us documentation to date, for an interesting and important experiment that he has started in the Tokelau Islands on behalf of the World Health Organization. In these islands, as well as many others in the Pacific, Aedes polynesiensis, a common day-mosquito, is the primary vector of Wuchereria bancrofti, causal agent of filariasis. The experiment attempts to compare the effectiveness of biological versus chemical control of this mosquito. Coelomomyces stegomyiae, a fungus parasite of Aedes, was introduced on Nukunono Atoll. Dieldrin-cement briquettes were placed in mosquito breeding places on Atafu Atoll, and the other of the Tokelau Group, Fakaofo Atoll, was left for a control. A first report, by Dr. Laird and Dr. D. H. Colless, of the University of Malaya, has been mimeographed as WHO document MHO/PA/93.59, and describes the experiment, and a popular article entitled The Tokelau Experiment, published in World Health 14: 12-15, 1961, mentions that a second visit has been made to the Tokelaus to check the results. The progress of the experiment is described as "encouraging". We are awaiting further reports with interest.

Maldive Islands:

Sizeable collections of marine algae, gathered by David Sigee on Addu Atoll (see ARB 108) are being identified by Roy Tsuda at the University of Hawaii. The vascular plants are being worked up by F. R. Fosberg. Lists should be ready for publication soon.

In my "Notes on Indian Ocean Atolls visited by the Yale Seychelles Expedition. I. The Maldive Islands, with special reference to the coral reefs," published in ARB 102, I neglected to cite a detailed discussion of Addu Atoll given by R.B.S. Sewell, "An account of Addu Atoll," John Murray Expedition, 1933-34, Scientific Reports, 1: 63-93, 1936.

Sewell also reported erosion on the west side of the atoll and attributed the fact that it was more pronounced than on the east side due to the greater strength of the southwest monsoon. Sewell's Plate VIII gives good photographs taken at a very low tide at or near YSE Sta. 25.

Alan J. Kohn

The research vessel, Te Vega, from Stanford University, California, cruised six weeks from March to May, 1964, throughout the Maldive Islands. Eight atolls from Tiladummati to Addu were visited. H. E. Hackett, graduate student from the Department of Botany, Duke University, Durham, North Carolina, participated as phycologist. A paper is being prepared on the floristic and ecological aspects of the marine algae. Thirty field stations were made including seven dredge hauls.

This visit to the Maldive Islands during the International Indian Ocean Expedition was made possible by the support of the National Science Foundation, as a part of the United States Program in Biology, and the courtesy of the government of His Highness Farid Didi, Sultan.

H. E. Hackett

(See below, Te Vega Cruises--Eds.)

Bahamas:

John Milliman will, this summer, continue his investigations in the southern Bahamas on Hogsty Reef and Inagua Island. This cruise, leaving on June 7, will include a stop on the eastern side of Inagua, where there is reported a "Lithothamnion-type ridge', an uncommon if not unique feature in West Indian coral reefs. We hope to have from him, in the not-too-distant future, a description of this reef.

Morant Cays, Jamaica:

Mr. R. W. Smith writes from Kingston, Jamaica, that he is organizing, on behalf of the Institute of Jamaica, a bird-banding program for Jamaica and the surrounding region. This program includes the banding of sooty and noddy terns on the Morant Cays, south of Jamaica. Smith made two visits to the Morant Cays in 1964, on the second of which he banded 2,000 terns. He expects to mark sooty terns with colored plastic leg-streamers, in the hope of getting some records of them at sea during the non-breeding season. Little is known of the habits or even the whereabouts of these birds during the time when they are absent from the islands where they breed. He is also making observations on the plants and we hope that he will make collections of these. Transportation to the Cays is available through the courtesy of the Jamaica Fisheries Department.

British Honduras Cays:

David and June Stoddart have just returned to Cambridge, England, from a month of investigations in the Cays off British Honduras, with special attention to recovery from the devastation by Hurricane Hattie (see ARB 87, 95). They were able to find very significant relations between vegetation cover and the preservation of land surface features, as well as making observations on the rate of consolidation of calcareous rubble in the zone just above high tide. A collection of plants has been received from them for identification by F. R. Fosberg. We hope to publish another of Stoddart's comprehensive reports before too long.

Publications

Carnival Under the Sea:

Dr. Catala's volume was published shortly after we included an announcement of it in ARB 108, p. 4. Both the English and the French (Carnaval sous la Mer) editions are beautiful examples of bookmaking,with magnificent color plates, black-and-white photos, and drawings. The French edition (68 F postpaid)may be obtained from Editions Sicard, 30 Rue Joubert, Paris 9, France. It is also on sale at the Aquarium de Nouméa, as is the English edition. The latter can also be ordered from the publisher, and paid for through the New York ($15.00 postpaid, registered) or London banks listed in the Subscription Announcement sent to all ARB readers last year. It is also available at the Steinhart Aquarium in San Francisco's Golden Gate Park, and at the B. P. Bishop Museum Bookshop in Honolulu for U.S. $15.00.

The Library of Congress has received and catalogued the English version, and printed catalogue cards may be ordered from its Card Division. LC Catalogue Card no. 64-66447.

Atoll bryoflora:

Much of the systematic work on the plants and animals of coral atolls has been of a rather preliminary nature, since both the taxonomy and the collecting have been in an active state, making publications of a definitive nature rather premature. However, the extensive collections made in the Micronesian atolls by the Collegiate Rebel Expedition in 1960 provided sufficient material to encourage H. A. Miller, H. O. Whittier, and C. E. B. Bonner to write a truly notable manual entitled Bryoflora of the Atolls of Micronesia (Nova Hedwigia, Beihefte 11: 1-89, 1963). Part I is a brief geographical, ecological and historical introduction, Part II is a detailed taxonomic treatment with keys to the 37 species of mosses, and Part III a similar treatment of the 25 hepatics. Geographical and distribution maps, photos of typical atoll situations, and 19 plates of magnificent analytical drawings of the species are provided. The authors are to be congratulated.

Clipperton Island

Quoted below is an extract from a letter from Rollo H. Beck, written at sea, enroute to the Galapagos, dated January 1, 1902, published in The Condor, 4: 50-51, 1902, that was not located prior to the publication of ARB 86. The quotation conveys some idea both of the atmosphere of the island and of the personality of this remarkable student and collector of Pacific Island birds.

"Around Clipperton Aestrelata phoepygia was frequently seen and the sooty terns wander hundred of miles from the island. The blue-faced boobies found at sea at this season are all young birds, that is, ten or eleven months old. Nearly all that we have seen at sea for the last three weeks have been in this plumage. Within 40 miles of Clipperton adult boobies were common, and of the thousands of blue-faced boobies seen on the island but one was seen in the spotted plumage.

"Clipperton Island! How I'd like to spend the month of January there with a good 8x10 camera. The family life of three or four species of birds could be pretty well photographed in that time. Of the blue-faced boobies (Sula cyanops) one can get a picture of one or a hundred or a thousand. Their tameness is occasionally decidedly annoying when one happens to be in a hurry and the nests are close together. It is advisable always to walk not closer than two feet from a sitting bird. With nests scattered around promiscuously it is a regular zigzag trail one makes. Sula nesiotes which is abundant also, does not nest till later though pairs of birds are holding down nesting sites and an occasional young bird unable to fly is noted.

"But the land crabs! Why, there are millions and millions of them and the astonishing effrontery of the intrepid thieves! I couldn't stand still two minutes before one would be clawing at my shoe, and from all directions the crabs would be edging toward me with a stealthy, sidelong, intermittent movement, and great, wide-open, bulging, staring eyes. As an instance of their amazing impudence I laid down three or four birds in front of me in order to wrap up some eggs. After wrapping three or four I glanced at the birds and an insatiable glutton of a crab had chewed off an eyelid of one while two others were picking at the wings of another bird and yards away other crabs were hurrying forward to participate in the toothsome repast. I scared back the nearest and felt a nip at my foot. There was an old reprobate trying to crawl into a little crack in my shoe, while near at hand came others to reinforce him. I actually had to wrap the birds up before doing anything else.

"Now if I wanted to give you a distorted version or exaggerate this statement in the least I would elaborate in the manner in which they carried off eggs while I was wrapping birds, but I haven't given you any thing but an abridged condensation of the facts! I wrapped the birds and eggs in a hurry and left the spot. But it is laughable to see a crab seize an egg as they do with boobies' eggs when occasion offers. They grasp it tenderly in that long arm and sidle off in a fashion highly amusing. The men on the islands tell me the crabs often take the young boobies from under their parents, and I can easily believe it. They also say but one young bird is reared though two eggs are usually hatched. I cannot recall now having seen two fair-sized young of either the blue-faced or variegated species, though I have seen plenty of nests of both with one young bird and two eggs.

"The land crabs are one of the unpleasant features to a collector down here."

In several papers on Clipperton, especially in the Symposium on Modification of biotic balance of island faunas and floras (Pacific Basin Biogeography, J. L. Gressitt, ed., Bishop Museum Press, 1963), p. 530, it was suggested that crabs might eat birds' eggs or even young birds. Finding confirmation in Beck's letter offsets somewhat the vexation of having missed it while preparing an "exhaustive" bibliography of Clipperton.

Central Pacific and Phoenix Atolls:

We have a Reconnaissance Survey Report on Howland, Baker and Canton Islands, made October 1963 by Holmes & Narver Inc. In addition to summarizing known information on these islands, especially Howland, this report presents considerable original data, mostly of interest to engineers, but some of it also of geological interest. Several shallow bore-holes were put down on Howland and Baker, and logs and descriptions of samples are included in the report. Shallow seismic surveys, using a "boomer" as the source of sound waves, were made on Howland and Baker. Colored air photos and ground photos, as well as some black and white photos and maps in some detail, are included. The information on Canton Island is of much less interest than that on the other two. It is hoped that the interest of AEC in these atolls does not presage their total destruction. Although they cannot be regarded as undisturbed islands, even in their present rather modified condition they are of great ecological interest. It would be a great pity if all such islands were regarded as waste land, available for any and all activities, however destructive. It seems clear that a few of these simple ecosystems should be preserved for the purpose, in the near or distant future, of investigating how ecosystems really work. If they are all destroyed we may regret it.

Fanning Island:

To one especially interested in intertidal erosion on coral islands a paper just received from Gerald J. Bakus, on The Effects of Fish-Grazing on Invertebrate Evolution in Shallow Tropical Waters (Allan Hancock Found. Pub. Occ. Pap. 27: 1-29, 1964), is extremely valuable. The author brings together the available information on "fish-grazing" from a wide range of papers, and adds the results of his own experiments carried out in 1963 on Fanning Atoll. The discussion and conclusions of this work are mainly devoted to selective and evolutionary effects on the biota of reefs, but the information assembled is also of great interest in relation to ecological and geological effects of grazing and gnawing by reef fishes.

Johnston Island:

Johnston Island probably has the distinction of being, of all the coral atolls, the most thoroughly modified by man. It now may join Clipperton, Arno, Onotoa, Raroia, Kapingamarangi and Ifaluk as one of the most completely known atolls. We have two comprehensive ecological reports at hand, one on land aspects, principally birds, the other on underwater ecology, mostly with reference to ciguateric (poisonous) fishes.

The Preliminary Biological Survey of Sand Island-Johnston Atoll, 136 pp., 1964, "prepared by staff Pacific Ocean Biological Survey Program Division of Birds Smithsonian Institution" (an unfortunate type of authorship, normally reduced for bibliographic convenience to "Anon."), very adequately summarizes what has previously been known of the land ecology of Johnston Island,and adds a great amount of information collected by the Smithsonian staff. This,naturally, is largely related to birds, as they are the principal focus of the project. A number of plants, and doubtless animals, new to the atoll are reported and lists of plants and animals known from the atoll are included as appendices. The plant list would have been improved a great deal if it had been submitted first to a botanist familiar with the plants of the area.

An Ecological Reconnaissance of Johnston Island and the Effects of Dredging, 90 pp., 1965, by V. E. Brock, R. S. Jones, and P. Helfrich, treats the marine environments in a similarly comprehensive manner, but with emphasis on fish. Very comprehensive lists of fishes, and brief ones of other invertebrates are provided, but algae, the presumed sources of the ciguatera toxin, are mentioned incidentally and not by name. Selected habitats are described and illustrated both by photos and by artists' sketches. Much attention is devoted to effects of dredging, and the Randall _/ Dawson_/ theory of the origin of ciguatera is further elaborated.

Both reports are abundantly illustrated with photos, maps, and graphs.

Intertidal erosion:

One of the most important questions in atoll geology and ecology is the nature and rate of intertidal erosion of limestone. A paper just received from E. P. Hodgkin, of the University of Western Australia (Zeitschr. Geomorph. N.F., 8: 385-392, 1964), reports the results of observations and experiments that suggest an average rate of erosion at near mean low tide level of about 1 mm per year, the rate decreasing toward high tide level. He ascribes this erosion to chemical corrosion plus the rasping activities of marine mollusks. The differential rate of erosion at different levels accounts very nicely for the widely observed phenomenon of notch-formation on these tropical limestone coasts.

Deposition and destruction of reef limestone:

The work of Tom Goreau on the fundamental processes of deposition of the calcareous skeletons of reef-forming animals and plants has, since we first became familiar with it, impressed us as about the best that is being done in the field. More unusual is Tom's ability to apply his microscopic-scale observations to the problems of formation of massive reefs and to relate these to environmental complexes and geographic situations. Now we are pleased to be able to call attention to two papers reporting aspects of this work. One is entitled Calcium carbonate deposition by coralline algae and corals in relation to their roles as reef-builders (Ann. N.Y. Acad. Sci. 109: 127-167, 1963). This goes into some detail concerning the environmental relations of the calcification processes, as well as their relation to photosynthesis, with rather little emphasis on the reef-building aspect. It will long remain a basic paper, essential to an understanding of reef ecology. The other paper is Control of coral reefs by boring sponges, in Mechanisms of hard tissue destruction, AAAS pub. 75: 25-54, 1963. This summarizes what is known of the mechanism employed in limestone destruction by clionid sponges, and examines in detail the great role these organisms play in the morphology and ecology of Jamaican reefs. We now must learn if these sponges have a similar influence on the reefs of the Pacific and Indian Ocean areas.

Reef island formation:

David Stoddart has sent a reprint of a paper on Storm conditions and vegetation in equilibrium of reef islands , published in the Proceedings of the Ninth Conference on Coastal Engineering, pp. 893-906, 1964. He discusses his investigations of the British Honduras Cays and the effects on them of Hurricane Hattie (see ARB 95, 104), and formulates a model of reef island formation. In this, in addition to the various physical conditions necessary for the accumulation of sediments to form bars, the establishment of vegetation is seen as the critical factor that enables such bars to grow further and become stabilized islets that accumulate additional sediments and may reach 10 feet or more in height, rather than the 3-5 feet possible without this assistance.

Alacran sediments:

We are delighted to be able to mention a fine addition to the knowledge of Alacran Reef (see ARB 93), a paper on Recent carbonate sedimentation on Alacran Reef, Yucatan, Mexico, by C. M. Hoskin, Publication 1089 of the National Academy of Sciences--National Research Council, 1963. The paper summarizes previous work and work in progress, but mainly reports the author's results during his investigations during the summers of 1959-1961. This comprehensive report is thorough, well-documented, and beautifully illustrated. It would be impossible to summarize it here, even its conclusions. Suffice it to say that many of the processes, both inorganic and organic, at work on coral reefs in the Yucatan area are discussed, and that this paper will be indispensable to any future workers interested in these problems and this area.

Maldive Atolls:

Eibl-Eibesfeldt, I., Im Reich der tausend Atolle, R. Piper & Co Verlag, München, 1964.

The Xarifa Expedition to the Maldive and Nicobar Islands (1957-1958), under the leadership of Dr. Hans Hass, has been mentioned in several Bulletins, especially ARB 91 and 94, p. 15 (review of Expedition ins Unbekannte). We now have another beautiful book on these and other islands. About half of it concerns the Maldives, and, like Dr. Eibl-Eibesfeldt's volume on the Galapagos Islands (1960), it combines narrative, background information on the islands, and many of the author's observations on reef animals, especially fish, in his role as "animal psychologist." This is the type of book of value to the scientist, with index and bibliography, and also of interest to the layman willing to take a little trouble and follow Dr. Eibl under the sea.

Diving now permits all sorts of scientific work among the coral biota and the author is an able guide. His most interesting studies of animal behavior are illustrated by many drawings and beautifully reproduced photographs in black and white and in color.

French Polynesia:

No. 6 of Cahiers du Pacifique appeared in June 1964 and, among many items of interest, includes several articles on corals and on the great reef of New Caledonia. The Fondation Singer-Polignac, which organized the New Caledonia 3-year survey and sponsors the Cahiers, will publish a series of technical reports on the New Caledonia and other studies. A "preliminary volume" in this series was issued in 1961 (Forest, J. and Guinot, D., Crustacés décapodes brachyoures de Tahiti et des Tuamotu, Expédition française sur les récifs coralliens de la Nouvelle-Calédonie...1960-1962, Vol. préliminaire, 1-195, Fondation Singer-Polignac, Paris, 1961, 18 plates).

Also more and more active is the French overseas research organization ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), and especially its Noumea research station, the Institut français d'Océanie. Its 1963 Annual Report, just received, cites many research programmes and notes improvements in available facilities and increase in staff. In 1963, M. Blanchon (Botany) visited the coral islets Surprise and Huon, and M. Huguenin (Phytopathology) also visited Surprise.

In its series of "Mémoires", the ORSTOM has just published an extensive report based on a 1959 survey:

Guilcher, A., Berthois, L., Le Calvez, Y., Battistini, R., and Crosnier, A., Les récifs coralliens et le lagon de l'Ile Mayotte (Archipel des Comores, Océan Indien) Mém. Orstom 11: 1-210, Paris 1965, 16 plates, 24 tables.

It is lavishly illustrated with charts, maps, tables and plates of photographs, and very detailed. Mayotte is a volcanic island with a barrier reef, and there is also a map and a brief description of the low coral Glorioso Islands. There is a comprehensive 4-page English summary. One might express mild criticism of the typography, the lines of text being too long for the size of the type; otherwise this is a splendid publication.

Some of the least well-known islands of the Pacific, Wallis and Futuna, are the subject of a monographic treatment in vol. 19 of the Journal de la Société des Océanistes. Unfortunately there is no map of these volcanic islands with barrier and/or fringing reefs. Vol. 20 of the same series has also just been received. In both volumes the extensive bibliography of Oceania initiated by Father P. O'Reilly is continued.

Micronesica:

The first volume, nos. 1 and 2, of this new Pacific journal (see ARB 100) is now at hand. It contains, among others, two papers on atolls: The social effects of Typhoon Ophelia (1960) on Ulithi, by W. A. Lessa, and The Crustacea Decapoda (Brachyura and Anomura) of Eniwetok, by J. S. Garth. The editor, B. C. Stone, has now left Guam for the University of Malaya, Kuala Lumpur, but still continues as editor of Micronesica. This issue is a highly creditable publication and gets the journal off to an excellent start.

Pacific Naturalist:

We are sorry to report that the attractive journal, Pacific Naturalist, has suspended publication. The last number, Vol. 4, no. 3, was issued February 20, 1964.

Manual for Tropical Herbaria:

The International Bureau for Plant Taxonomy and Nomenclature, with the financial assistance of UNESCO, has just published vol. 39 of Regnum Vegetabile, by F. R. Fosberg and M.-H. Sachet, with the above title (132 pp., 16 figs.). The Manual includes extensive instructions on plant collecting which will be of use on coral atolls as well as in all other types of tropical vegetation.

Personalia

H. A. Miller, authority on bryology of atolls, has spent the second semester of this academic year as visiting professor in the College of Guam.

Henry O. Whittier, bryologist, is now located at the New York Botanical Garden, after a moss-collecting trip to Tahiti.

Ernani Meñez, who collected algae in the atolls of the Carolines on the Collegiate Rebel Expedition in 1960, is now working at the Smithsonian Dept. of Oceanography Sorting Center, Washington, D. C.

Yale Dawson, former editor of Pacific Naturalist (see above), is spending the summer at Humboldt State College, Arcata, California, and will join the Smithsonian staff in Washington at the end of the summer. We can expect a great revival of interest in marine Algae at the National Museum beginning at that time.

F. R. Fosberg and Michael Evans, of the Pacific Vegetation Project, will go to Guam in June and will visit as many of the islands in Micronesia as feasible during the next two months. Mr. Evans will remain in Guam to continue collecting plants with as much information as possible on the medical and dietary uses by the local people.

Items of General Interest

Research Station in West Java:

We have heard, indirectly, that the Indonesian Institute of Biological Science is establishing a small research station on Poeloe Poetjang, a small coral island just off the coast of the Ujong Kulon Reserve, near the western tip of Java. This small island, a flat patch of coral sand with a low limestone ridge near one end, has one of the few remaining bits of native lowland forest in Java. This forest has been the subject of study by the botanists from the Bogor Herbarium, especially Dr. A. Kostermans and his students, for a number of years. It has yielded several new trees and specimens of others that have not been seen for a hundred years. The new station should provide facilities for scientists who wish to continue these studies, as well as for those studying the coral reefs and the fine nature preserve on the nearby Java mainland. We wish the Institute well in this new enterprise.

South Pacific solar eclipse stations:

Dr. Gerald Mulders, of the Astronomy section of NSF informs us that two atoll stations are being set up for investigation of the total solar eclipse on May 30-31 in the South Pacific. One of these is on Manuae in the Cook Islands, the other on Bellingshausen, in French Polynesia. Parties of astronomers from several nations will share these facilities. Perhaps bits of information of other than an astronomical character may result, in addition to their main objectives.

Te Vega Cruises:

Thanks to Don Abbott we have received copies of the first 18 (minus one not yet duplicated) installments of Dr. Rolf L. Bolin's very entertaining and informative General Narrative of the first seven cruises of the Hopkins Marine Laboratory's research vessel, Te Vega; also Abbott's account of the scientific aspects of Cruise 5. These seven cruises were actually segments of a single complicated trip across the Pacific to the Solomon Islands, New Britain, Singapore, the Philippines, Indonesia, Thailand, the Indian Ocean, Ceylon, Madagascar, the Comoro Islands, the Maldives, back to Singapore, Philippines, Rabaul, and the Solomons, including the fascinating elevated coral islands, Rennell and Bellona. Cruise 8 will bring them back across the Pacific to Monterey, with visits to various of the central Pacific atolls. The different cruises were marked by the presence of different guest investigators and different groups of students. Primary attention seemed to be on hydrographic stations with plankton tows, deep-water trawling and dredging, and ichthyological collecting. However, many islands were visited, a few of them atolls, and much collecting was done on coral reefs, especially of fish, mollusks, and algae of the genus _Halimeda_ (by Dr. Llewellya Hillis Colinvaux). The combination of serious research by advanced investigators and work on graduate problems by students, lectures on problems and fields of interest in marine biology and biological oceanography by staff and visiting scientists and guest lecturers, and continuous exposure to the ecosystems under study would seem to provide an ideal system of training for students and stimulus to mature scientists. Perhaps even a few future Darwins might result. It is hoped that investigations of land aspects of coral islands may be included as a part of future cruises, and that papers suitable for ARB may result.

Smithsonian Institution:

From the Smithsonian Institution come several items of interest. One is the establishment of a Sorting Center for specimens of marine organisms collected in the various oceanographic programs now under way, such as the International Indian Ocean Expedition. The U. S. National Herbarium is moving from the old castle across the Mall into new and more spacious and convenient quarters on floors 4 and 5 of the new west wing of the Natural History Museum. An expanded interest in ecology and tropical biology is being developed in the Smithsonian. We hope that this will extend to the ecology of coral atolls and islands.

Gilbert Islands Study:

We have just had the visit of M. Jean Paul Latouche of the French CNRS (Centre National de la Recherche Scientifique), who is on his way to the Gilbert Islands for a two-year stay. He plans to study social anthropology, land tenure and ethnobotany on Abemama, Kuria and Aranuka. Mme Nicole Latouche will be preparing a monograph on the Gilbertese system of Cooperatives.

Erratum:

Our attention is called, by Mrs. Jane Cooper, to the fact that in ARB 105, pp. 2 and 11, her affiliation is given as "Department of Cooperative Societies, Suva, Fiji", while, in fact, she is a research associate of the University of Hawaii. The Suva address is merely her mailing address, as it is her husband's place of employment. We are glad to make this correction.

Smithsonian Bird Banding Program:

Results from the bird banding and marking activities of the Smithsonian Pacific Ocean Biological Survey Program (see ARB 108) are already beginning to come in. Large numbers of sea-birds are being marked with bands and with colored plastic leg streamers and released on various islands of the central Pacific. On March 1 we received a letter from Dr. Philip S. Humphrey, head of this program, indicating that cooperation in reporting marked birds and returning bands is enthusiastic in all parts of the Pacific. Excerpts from many letters are quoted. As a consequence of this the Smithsonian has decided to send out an occasional newsletter to such cooperators to keep them informed as to the results. Identification material and colored slides on the Pacific sea-birds are being prepared and made available to schools to encourage people to interest themselves in these birds and to report sightings back to the Smithsonian. We are reproducing here the notice that has been circulated announcing the marking program and requesting cooperation, in case any of our readers have not seen it.

ATTENTION!

Hundreds of thousands of far-traveling ocean birds of many kinds are being captured, marked, and released on mid-Pacific islands in a widespread study of seabird migration by the Smithsonian Institution, Washington, D.C. Although it is known that some kinds of birds perform remarkable annual migrations of 10,000 miles or more over the North and South Pacific Oceans, the regular travels of most species are unknown or poorly understood.

To learn more about the migrations of seabirds, Smithsonian ornithologists have captured and marked over 300,000 birds of 28 different kinds in the Central Pacific with standard, numbered, United States Fish and Wildlife Service aluminum legbands. Of these, over 60,000 have been marked with 4 inch colored plastic leg-streamers.

Anyone coming into the possession of a banded dead bird in the Pacific Ocean Area is asked to cooperate by returning the band, together with time and place of recovery, as instructed on the band. For live birds, only the band number together with time and place of capture need be sent to the directed address, after which the bird should be liberated so that its further travel may be traced.

Anyone sighting a bird with a colored leg-streamer anywhere in the Pacific Ocean Area is asked to cooperate by recording the name or description of the kind of bird wearing the streamer, the color of the streamer, the date seen, and the latitude and longitude or approximate location of sighting. All information on birds with colored leg-streamers should be sent as soon as possible to:

Division of Birds
Smithsonian Institution
Washington, D. C. 20560

EACH COOPERATOR WILL BE ADVISED WHERE THE BANDED OR COLOR-MARKED BIRD WAS TAGGED.

--YOUR HELP IS NEEDED--

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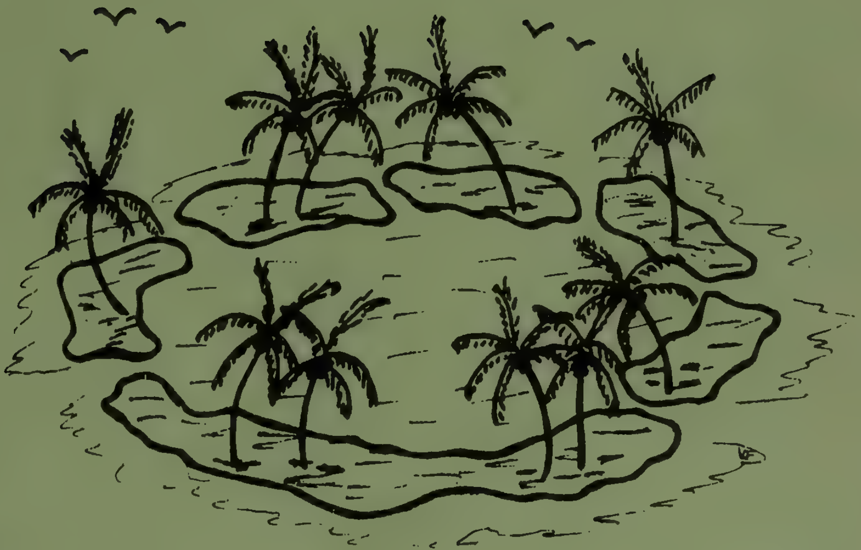
No. 113 December 31, 1965

ATOLL RESEARCH BULLETIN

Terrestrial Sediments and Soils of the Northern Marshall Islands

by

F. Raymond Fosberg and Dorothy Carroll



Issued by
THE PACIFIC SCIENCE BOARD
National Academy of Sciences—National Research Council
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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past eighteen years.

The preparation and issuance of the Atoll Research Bulletin is assisted by funds from Contract Nonr-2300(12).

The sole responsibility for all statements made by authors of papers in the Atoll Research Bulletin rests with them, and they do not necessarily represent the views of the Pacific Science Board or of the editors of the Bulletin.

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2101 Constitution Ave., N. W.
Washington, D. C. 20418, U.S.A.

Terrestrial sediments and soils of the northern Marshall Islands[*]

by

F. Raymond Fosberg and Dorothy Carroll

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[*] Publication authorized by the Director, U. S. Geological Survey

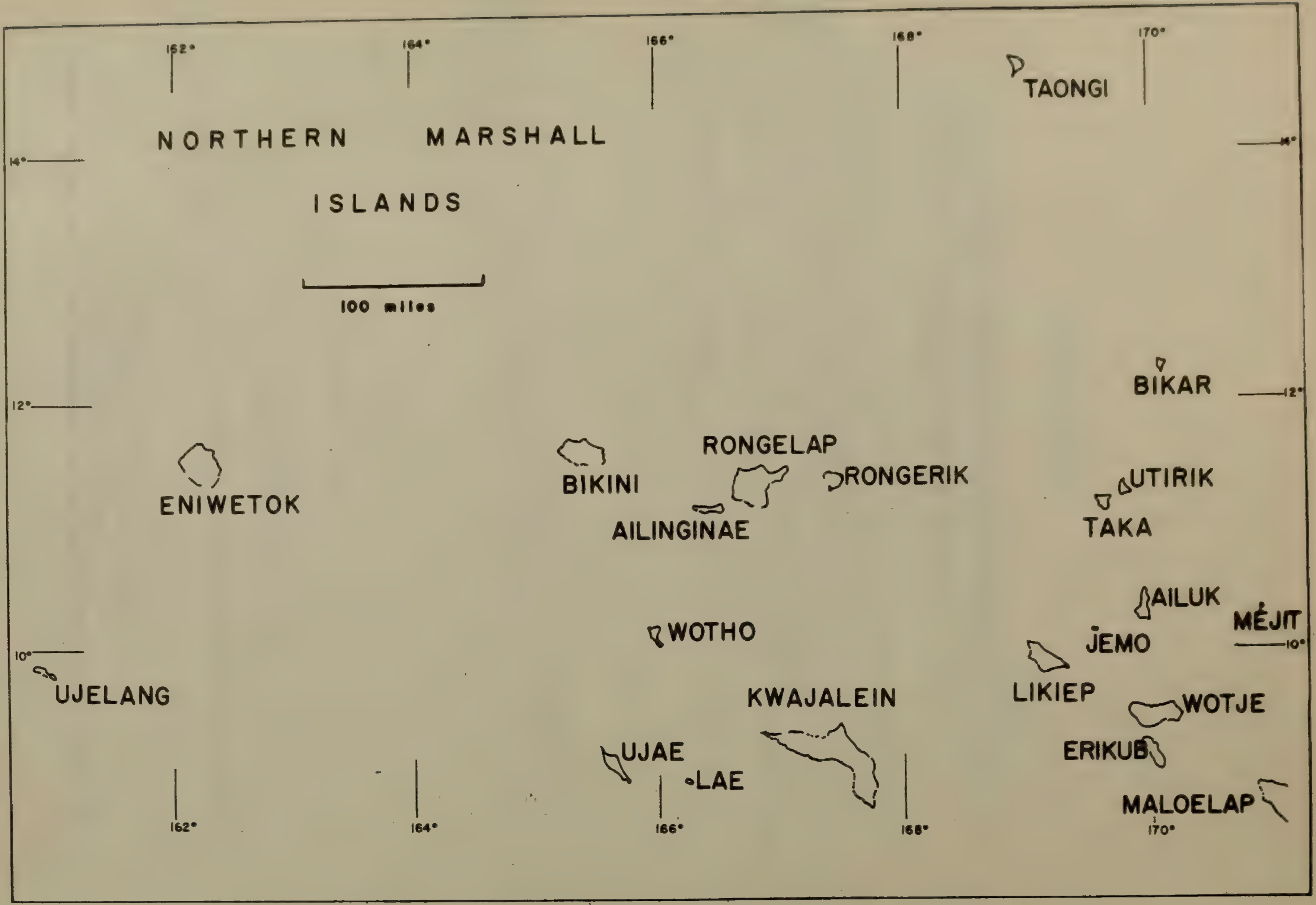
NORTHERN MARSHALL
ISLANDS
100 miles
162°
164°
166°
168°
170°
14°
12°
10°
TAONGI
BIKAR
ENIWETOK
BIKINI
RONGELAP
RONGERIK
AILINGINAE
UTIRIK
TAKA
AILUK
MĖJIT
J̇EMO
WOTHO
UJELANG
KWAJALEIN
LIKIEP
WOTJE
ERIKUB
UJAE
LAE
MALOELAP

FIGURE 1. MAP OF THE NORTHERN MARSHALL ISLANDS

PREFACE

Parts of the information in this paper have been previously included in a U. S. Army Intelligence document (Fosberg and others, 1956) but are presented here in somewhat modified form to be generally available to the scientific public. The present paper was first written in 1954 for publication as a Professional Paper of the U. S. Geological Survey, under which auspices the work was done. Extended delay and the prospect of still more finally brought about the decision to publish it in the Atoll Research Bulletin, thus avoiding continued inaccessibility of the information. We apologize for the long delay, and for any failure to take into account literature published after the paper had reached its present form as well as later field work, the results of which have not yet been analyzed.

The U. S. Board on Geographic Names has, since the 1956 publication, issued decisions on Marshallese place names which take up different spellings for many of the islet names used in 1956, different names altogether for some, reverse the application of several names, and in at least one case (Jaboero and Jabwelo), adopt variants of the same name for two different islets in the same atoll (Bikar). In order to reduce confusion resulting from place names differing in the two reports, a complete list of the islets of all the atolls for which maps are provided in this paper is given in Appendix III, with parallel columns giving names adopted by the Board on Geographic Names and used in this paper, those used in the 1956 maps (Fosberg and others, 1956), and those from a manuscript list supplied by E. H. Bryan, Jr., of the B. P. Bishop Museum. These latter were compiled by Bryan in consultation with Dr. Leonard Mason of the University of Hawaii, and a number of Marshallese informants from most of the atolls concerned. It is hoped that this will make the present paper intelligible to those who have used the Army publication (Fosberg and others, 1956), as well as to Marshallese and others familiar with the names actually used in the islands.

The maps (figures 5-15) are adapted by change of islet names from originals prepared by F. Stearns MacNeil for the 1956 report (Fosberg and others 1956, figs. 2-13) which were there wrongly listed as based on Hydrographic Office charts. These maps were based on air photographs.

Grateful acknowledgment must be made to Prof. E. L. Stone, Jr., Dr. K. O. Emery, and Mr. Z. S. Altschuler who reviewed and made suggestions on an early draft of the manuscript, and many of whose suggestions have now been incorporated. The editorial criticism of the present manuscript by Miss Natalie Jones and by Mrs. Wenonah E. Berquist is greatly appreciated. The figures were redrafted by Miss Barbara Geyer. Great credit is due our several typists who have produced the several drafts of the manuscript, especially Mrs. Josephine Q. Barton, who did much of the final version, and to Mrs. Ann Chamberlain, who cut the stencils. J. Anthony Denson gave valuable advice and much help with improved prints of many of the photographs as did Norman Prime. **Finally, we wish to thank Dr. Marie-Hélène Sachet, whose assistance with the manuscript at all stages has been indispensable.**

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ABSTRACT

An investigation was made of surface geology, islet formation, sedimentation, and physical and chemical nature of loose sediments on atolls of the northern Marshall Islands.

Islets in their present form are of three types, based on origin and position: (1) formed by partial removal by planation of preexisting reef platform, leaving remnants around which sediments accumulate; (2) formed by accumulation and stabilization of detrital deposits on reef flats, and (3) formed by accumulation of detrital deposits locally within the lagoon, especially just inside channel mouths. Physiographic features of islets--erosion ramps, sand lobes, sand horns, sand aprons, tidal and storm beaches, rock shores, beachrock, marginal ridges, dunes, interior flats and depressions, parallel ridges, and blowdown mounds are described, and their principal organic components listed.

Mechanical analyses were made of samples of beach sands and soils. Size classes were correlated to some extent with faunal composition of the materials, small Foraminifera accounting for a large part of the 2-1 mm and 1-0.5 mm sizes. Larger fractions were made up of whole or broken corals, large fragments of algae, and large shells. Fractions smaller than 0.25 mm are mostly of broken unidentifiable fragments.

The frequency of the modes (or maximum grades) in the size distribution in the beach sands is as follows: 2 to 1 mm (-10 + 18 mesh), 21 percent; 1-0.5 mm (-18 + 35 mesh), 48 percent, and 0.5 -0.25 mm (-35 + 60 mesh), 17 percent. In none of the sands is there a primary mode in the + 0.125 mm, + 0.062 mm, or less than 0.062 mm fractions.

Determination of mineral composition of the sediments by X-ray diffraction shows a correlation of calcite:aragonite ratios with original biological composition rather than with degree of weathering. Considerable magnesium is present in the calcite, especially in sediments largely made up of algae, and in the middle size grades of the sediments.

Median grain diameter, sorting coefficient, and skewness were calculated for the samples. Size distributions, illustrated by histograms, show that the beaches are, in general, similar from islet to islet, even though the individual samples from a beach may vary. Beach materials do not become much smaller than 0.25 mm grain diameter, or else the smaller material is lost by winnowing by waves and currents. Skewness in most sands is positive, indicating admixture of coarse material and lack of fines.

The soils resemble beach materials in their mechanical analyses, but the texture range is enormously wider and the range in sorting is also wider. The soils are irregularly stratified, commonly with weak profile development, but with strata mostly representing stages or events in deposition. Most soils can be assigned to three previously described series, the Shioya, Arno Atoll, and Jemo, but certain highly organic soils could not be definitely assigned to series. These

series differ chemically in the amounts of organic matter in the A horizons and the presence or absence of a phosphatic B horizon. A_0 horizons and B horizons are found only in the Jemo series soils, usually correlated with the presence of Pisonia forest vegetation.

Chemical analyses show that vertical trends in the amounts of certain elements in the different layers are discernible: magnesium increases downward; calcium is lowest in layer 1 because of the higher organic content, and this is especially obvious in the Jemo series. Of the minor elements, iron, cobalt, nickel, molybdenum, and zinc are much higher in the raw humus layer of the Jemo series profiles, suggesting accumulation of these elements by the Pisonia tree in its tissues. Most of the metallic constituents, except calcium and magnesium, are present in extremely small amounts. Serious deficiencies in most mineral nutrients of plants, except calcium, magnesium, phosphorus, and possibly potassium, would be expected. These might be intensified, in some cases, by the strongly calcareous environment.

pH values are high in all layers except the raw humus layer of the Jemo soils where the pH ranges between 4 and 6.

INTRODUCTION

by F. R. Fosberg

In spite of the great amount of attention that has been paid to the geology of coral atolls, relatively little detailed information is available on the chemical and physical properties of the sediments which make up atoll islets, on their weathering, their origin, their stratigraphy, or the conditions under which they were laid down. The availability of a large series of samples representing sections down to the water table or to bedrock in the northern Marshall Islands, and of a considerable body of chemical and mechanical analyses of these samples has made it possible to remedy this deficiency to some extent. The study of this material has yielded a picture of the general nature of the sediments, but has also brought out certain problems which only further research will solve.

Field work

The material considered here was collected on a reconnaissance survey of the military geography of a number of the atolls in the northern part of the Marshall Islands, and this paper is a by-product of that investigation. This survey was carried out by a field party of the U.S. Geological Survey working for the Office of the Engineer, Headquarters, U.S. Army Forces, Far East, during 1951 and 1952. Most of the soil samples were collected by F. R. Fosberg; some were collected by Ted Arnow, hydrologist of the party, during the digging of wells. Beach sand samples were gathered by F. Stearns MacNeil and Charles G. Johnson, geologists. The sampling is admittedly inadequate because of the broad nature of the assignment and the fact that only minutes, hours, or at the most, parts of a few days, were available for work on soils of any given islet.

The circumstances of the survey (Fosberg, 1955) were such that it was possible to obtain a scattering of material from over a wide area but impossible to study any single atoll or islet in detail. Furthermore, lack of any previous soils work in this area made the sampling, especially in the earlier atolls visited, a random procedure rather than one designed to bring out any specific type of information or to investigate particular problems.

Laboratory work

After the samples collected had been brought in, described, and the soils assigned to previously known or to new atoll soil series, it was felt that for the purposes of the military geography report (Fosberg and others, 1956), more should be known about the physical properties of the sands and soils and that some chemical studies should be made in order to understand the severe agricultural limitations of these soils. A selection of samples was made that it was hoped would prove representative of the soils in the area studied. It was unfortunate, but unavoidable, that this selection had to be made before the problems regarding these soils were clearly formulated. Because of the unusual interest of the phosphatic materials a more complete representation of them was analyzed than of the other materials. The lower layers of all the types of soil profiles are poorly represented in the analyses. Organic carbon in less humic soils was not determined. Future work, on more critically selected complete profiles down to ground water in all the series, is much to be desired.

Previous studies

Studies have been made on various atolls as part of the Coral Atoll Program of the Pacific Science Board (Stone, 1951a, 1953, Cloud, 1952; Hatheway, 1953, 1957; Fosberg and Sachet, 1953; Newell, 1954b, 1956; Sachet, 1955, McKee, 1956, 1958; Fosberg, 1957b; Catala, 1957; McKee and others, 1959; Tracey and others, 1961), on Bikini and nearby atolls by the Crossroads Operation Survey and subsequent surveys (Emery, Tracey, and Ladd, 1954), and on Ulithi Atoll by Schlanger and Brookhart (1955). These, as well as the investigations reported here (also reported in Fosberg, 1954, 1957a; Fosberg and others, 1956), make it possible to know what to expect in the way of soil and sediment types, as well as areal and stratigraphic arrangements of sediments, and to define at least some of the problems which should be investigated. Certain earlier literature, especially the publications resulting from the expeditions that made the boring on Funafuti in 1896 (Sollas and others, 1904), those of Wentworth and Ladd (1931) on the Central Pacific Atolls, and those of Kuenen on East Indian Atolls (1933, 1950) also contribute important information. The paper by Ladd, Tracey, Wells, and Emery (1950) is of special significance in understanding the origin of the sediments with which we are dealing.*/

Land areas

The Marshall Islands comprise 31 atolls and single low islands scattered over an area nearly 700 miles from north to south and about the same distance from west to east, between 4°34' N. and 14°43' N. and 160°48' E. and 172°10' E. They form two very irregular, roughly parallel chains that trend northwest-southeast. The western chain is called Ralik, the eastern Radak. This arrangement, however, is difficult to discern on a map. Before reading further, the reader is urged to consult the section "Synonomy of place names" at the end of the report.

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*/ Since this paper reached its final form, a number of pertinent and important papers have appeared, such as Blumenstock, ed., 1961, Guilcher et al., 1965, Hoskin, 1963, McKee, 1959, Newell, 1960, Russell, 1962, 1963 and Stoddart, 1960, 1962a, 1962b, 1963, 1964, 1965. None of them, however, appear to necessitate serious modification of interpretations presented here, though not all these authors would agree completely with our interpretations.

The present paper is concerned only with those 21 atolls or islands lying north of 8°30' (fig. 1), hereafter referred to as the northern Marshall Islands. These are, from north to south and west to east, Taongi (Pokak), Bikar, Eniwetok, Bikini, Ailinginae, Rongelap, Rongerik, Taka, Utirik, Ujelang, Wotho, Likiep, Jemo, Ailuk, Mejit, Ujae, Lae, Kwajalein, Wotje, Erikub, and Maloelap, 21 in all. Maloelap could equally well be included in the Southern Marshalls. Observations were actually made and material collected for study on Taongi (Pokak), Bikar, Taka, Utirik, Ujelang, Wotho, Likiep, Jemo, Ailuk, Ujae, Lae, and Kwajalein. In addition, use has been made of certain observations, analyses, and collections made by the geologists of the Crossroads Survey in Eniwetok, Bikini, and nearby atolls in 1946.

The land on these atolls is nowhere much above sea-level, averaging between 4 and 10 feet above mean low tide. The highest elevations are beach ridges, piled up by storms, and sand dunes. The highest recorded elevation in the group is a sand hill or beach ridge on Likiep Atoll, variously said to be 25 to 37 feet high. These higher features are all composed of loose sediments. The consolidated platforms on which much of this loose material rests are mostly between mean low tide level and about 6 feet above, with a very few humps extending up a few feet more (only seen on Bwokwla (Bokla or South) Islet, Taongi (Pokak) Atoll). The relationship of the individual islets of an atoll to the underlying reef is shown diagrammatically in figure 2.

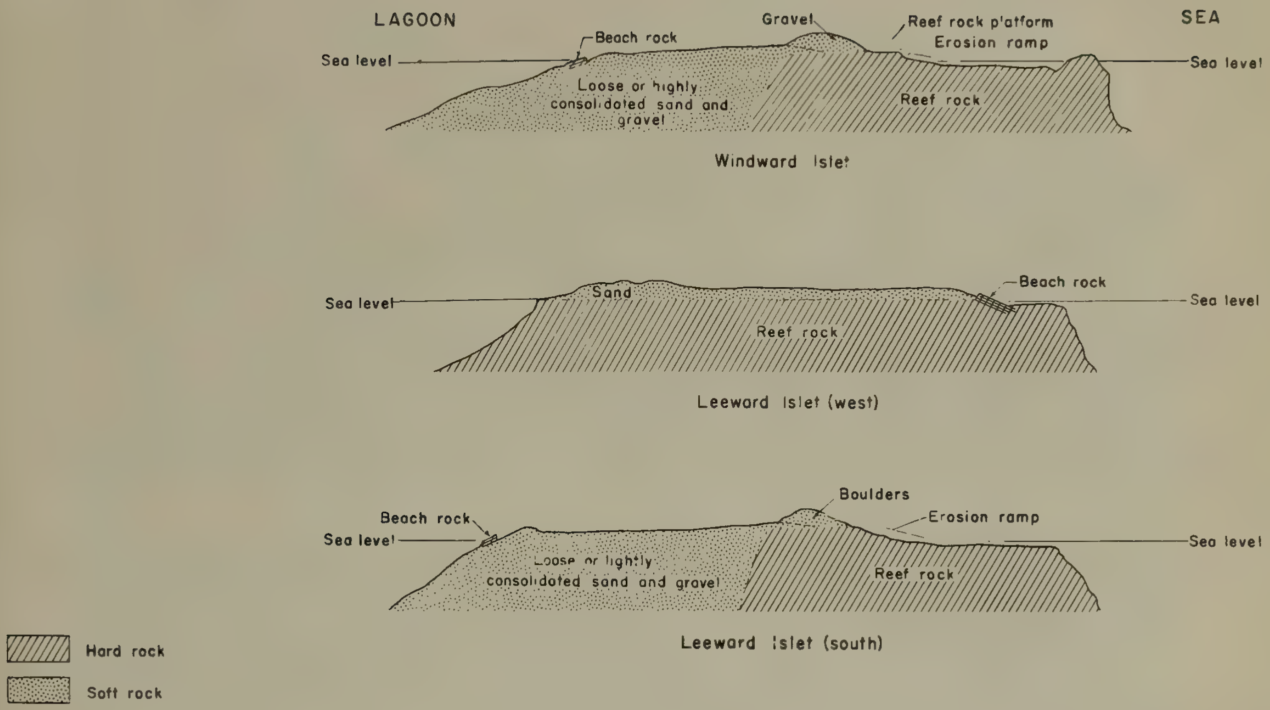
Climate

The climate of the northern Marshall Islands is tropical, with very little variation in temperature. The extreme variation is from about 68° F to 97° F, but most of the time the range is from 76° F to 87° F, with a mean of about 82° F. The sunlight is intense and the sky usually characterized by considerable scattered cumulus cloudiness. Really cloudy days are rare but do occur. The islands all lie in the trade-wind belt, with prevailing winds from the east to northeast, strongest in the winter and spring months. Calms, weak, variable winds or southeasterly winds may occur from June to September. Storms are likely to come from the south. Typhoons are rare but sometimes extremely severe and destructive. These, also, usually travel in a general northerly direction and rotate counterclockwise. Both typhoons and trade winds are of great importance in determining the topography of the islets and the nature and distribution of sediments.

Available moisture is of primary importance in the weathering and leaching of sediments, soil formation, and in determining the nature and luxuriance of vegetation. The islands are relatively dry, compared to the southern Marshall Islands and the Caroline Atolls. The rainfall decreases rapidly to the northward, with a total range from a recorded extreme of 149 inches to 25 inches or less, possibly almost no rain in very dry years in the northernmost of the atolls. The annual averages range from an estimated 40 inches in the north to a recorded 106 inches in the south. The rainfall is strongly seasonal, December to April being the driest months, June to November the wettest. The rainfall in any one atoll varies tremendously from year to year, even in corresponding months. The extreme annual figures recorded for Ujelang are a low of 52 and a high of 116 inches. Comparable figures for Kwajalein are 82 and 149 inches for Eniwetok, 24 and 73 inches. It will be noted that none of these figures indicate a dry climate as understood in continental regions, but with the special soil conditions on atolls, the lower figures are correlated with an aspect of relative aridity in the landscape. The relative humidity is ordinarily fairly high, as might be expected from the proximity of the ocean, the lowest monthly mean recorded being 66 percent for noon readings on Eniwetok. In the more northerly atolls it doubtless reaches a lower figure than this occasionally.

Tides

Tidal data for coral atolls are generally unsatisfactory, as there are few stations and the lagoons with openings of different sizes introduce complications. In the U.S. Coast and Geodetic Survey tide tables for 1966 information for the Marshall Islands is calculated from predictions made for Kwajalein. There is no indication as to whether the observational data on which these predictions are based were collected in the lagoon or on the windward or leeward seaward coasts. Because of the peculiar geographic relations introduced by the difference in size and in number of openings into a lagoon, the tidal behavior, and especially the lag in tidal events inside compared with outside of the lagoon, will be highly variable from atoll to atoll. An extreme example may be cited, that of Taongi (Pokak), where the opening is so small that the tide level inside the lagoon never falls significantly below the level of the reef, though outside the spring tide range is 4.7 feet. Keeping in mind these reservations, data from the tables for 1966 show that the mean tide ranges, presumably outside the lagoons, in the northern Marshall Islands are from 2.7 to 3.7 feet, the spring ranges, 3.9 to 5.1 feet, the maximum difference in one day, 6.6 feet; the minimum difference between high and low, 0.0 foot, the minimum difference in one day, 0.0 foot. These figures are, of course, also subject to variation due to weather conditions both local and general, or even elsewhere in the Pacific. It is probable that careful studies would show that significant average figures for any given locality could be derived from the vertical distribution of certain sessile organisms in the intertidal zone, reflecting their capacity to endure exposure to air. Such studies are not, to the best of my knowledge, available yet in sufficient detail to be used.


LAGOON
SEA
Gravel
Reef rock platform
Erosion ramp
Beach rock
Sea level
Sea level
Loose or highly consolidated sand and gravel
Reef rock
Windward Islet
Sand
Beach rock
Sea level
Sea level
Reef rock
Leeward Islet (west)
Boulders
Beach rock
Erosion ramp
Sea level
Sea level
Loose or lightly consolidated sand and gravel
Reef rock
Leeward Islet (south)
Hard rock
Soft rock

2. Diagrammatic cross sections of islets on windward and leeward reefs of atolls showing positions of reef rock, unconsolidated materials, beach rock, rock platforms, and erosion ramps.

PART I: GEOLOGY

by F. R. Fosberg

The geology of these atolls has been described in several publications (Tracey, Ladd and Hoffmeister, 1948; Nugent, 1946; Emery, Tracey and Ladd, 1954; Fosberg and others, 1956, p. 74-132; and Fosberg, 1957 a). A summary of the geology follows.

Physiographically an atoll is the upper calcareous part of a broadly conical or irregularly pyramidal mountain mass rising from the floor to the surface of the ocean. Only the top of this is usually considered, geographically, and of this only the part which breaks the surface of the sea need be discussed here. Thus restricted, the northern Marshall Islands are a series of narrow platforms or reefs, usually irregularly ring-shaped or polygonal, commonly enclosing a shallow body of ocean water called a lagoon (pl. 1A). Of these platforms by far the largest areas lie at or just above or below tide level and are called the reef flat. The outer edge of this either falls off abruptly, as on leeward sides, or is elevated in the form of a low ridge, as on windward sides. The inner margins, where not occupied by islets, shelve off into the lagoon. The surface of the reef flat may be relatively smooth or locally quite rough or strewn with great boulders. Scattered along these platforms are areas that rise above high-tide level, called islets (perhaps a better term is the Polynesian word motu, but even this is not completely devoid of ambiguity) (pls. 1, 2). These islets, though forming only an infinitesimal part of the area and bulk of atolls, are in many respects the most interesting one, and that with which this report is principally concerned.

The entire structure of an atoll, except the deeply submerged part of the foundation, is made up of organic limestone sediments, either loose or variously consolidated. Deep borings on Bikini and Eniwetok have given much information on the nature of the sediments making up the part below sea level (Emery, Tracey, and Ladd, 1954; Ladd and others, 1953; Ladd and Schlanger, 1960.) These are mostly unconsolidated material, and extend downward to more than 4,000 feet below sea level. Some layers are consolidated or partly so. Most of the material resembles that deposited in the lagoon today. A few traces of carbonaceous material, with land plant pollen and fossil land and fresh-water shells, suggest that some of these sediments were once terrestrial and supported vegetation.

Origin of the reefs

Before considering the morphology and structure of the islets, themselves, it will be necessary to give brief attention to the origin and nature of the reefs and the materials of which they are composed. This is, in certain aspects, a highly controversial subject, and for more adequate treatment of it reference may be made to the publications cited above. The limestone is made up of the skeletons of lime-secreting animals and plants, mainly corals. Foraminifera, and those algae which possess hard skeletons (see p. 56-74). These animals and plants add to the rocky structure on which they grow in two different ways. Some of them are firmly attached and cemented onto the rock, adding by the growth of their skeletons to the material of the rock itself, either in the form of crusts or as outgrowths. Storm waves may break these off. Others are either free or loosely attached, becoming free when they die. The loose material so formed, as well as that resulting from breakage, accumulates on the reefs, on the islets, in the lagoons, and on the submarine outer slopes of the atolls. That on the islets comprises the sediments that are the subject of this report.

The firmly attached organisms are of many different shapes and grow together very abundantly in the warm seas of the tropics. Attaching themselves to each other, as well as to the rocks, their skeletons form a rigid latticework of limestone, which may be filled in either by growth or by deposit of loose sediments in the interstices. Most of the corals (pl. 3) are branched; often they are miniature treelike structures that are rather fragile and easily shattered or torn loose by storm waves (pl. 3A, B). Some of those exposed to direct wave action have more compact growth forms and are more resistant. By themselves, however, most of the corals would not be able to make the stable structure known as coral reefs. The function of cementing and binding these corals together into a massive rock is performed by certain of the calcareous algae (plants) (pls. 4, 5) and by certain colonial hydrozoans (Millepora) (animals) related to corals, which grow with no fixed or definite forms but which make a shapeless hard crust over the surfaces of the other animals, smothering them, filling in the holes and spaces between them, thus presenting a smoother and more resistant surface to the force of the waves. These binding organisms, especially the plants, thrive best in the roughest, most thoroughly aerated water. For this reason the firmest structures of the atolls are on the windward sides where the swells break continuously. Growth of reef-building organisms, generally, is faster on the outer edges of the reefs where waves break, thus building up these portions more rapidly than the more protected parts (pl. 5A, C). Usually the most perfect and most intricately branched coral skeletons may be found in quiet places, such as lagoons (pl. 3), or in water below the active turbulence zone on the outer slopes, where they are not smashed by heavy waves. However, the greatest amount of limy material is added on the outer edges of the reefs. This area is also the source of much of the fragmentary material which forms the sediments that fill large parts of the reef structure. It has been shown by the studies at Bikini (Ladd and others, 1950) that loose material detached from the reefs, especially on the windward sides, is carried by currents, waves and winds and deposited in various other parts of the atoll structure to form the sediments of which the atoll is largely composed. Any hole in the latticework, any protected pool or cavity, as well as the lagoon itself, tends to be filled in by this loose material. This debris may become cemented either by growth of such binding organisms as those mentioned above or by deposition of lime from the sea water, thus adding to the strength of the reef structure, or it may remain indefinitely as unconsolidated sediments protected from wave action by the surrounding rigid framework of the reefs.

It might well be supposed that these masses of limestone had grown up directly from their volcanic foundations until they reached the surface of the ocean. This cannot be true, however, because none of the important reef-building organisms can thrive in water too deep to permit a significant amount of light to reach them. The actual limits of growth of these organisms vary greatly, but there is certainly little material added below a depth of 300 feet, and the important addition is above 150 feet. These facts have been known for a long time and recent investigation has tended to confirm and amplify previous knowledge of these limitations. Therefore, it is clear that other principles must be involved in the presence of enormous masses of limestone below the limits of effective penetration of light into sea water. These principles have been the center of violent scientific controversy for more than a hundred years, and only the investigations of the last 20 years have brought matters to a point where a brief, reasonably convincing generalization can be made of the mode of origin of coral atolls.

There now seems little doubt that all reef growth took place in shallow water and that the volcanic foundations of the atolls have subsided with relation to sea level, the relative change in elevation being slow enough to allow upward growth to keep pace with the subsidence. In this way the zone of active growth would have remained within the levels where light was sufficient. Whether this relative change was due to actual subsidence of the volcanic islands or to worldwide changes in sea level is not certain, but it is probable that both took place. During the glacial periods, especially, there are known to have been considerable shifts of sea level and unquestionably these have had a profound effect on the present form of coral islands. It is believed, for example, that within the last few thousand years there has been a fall of approximately 6 feet (or 11 feet according to some authorities, especially Fairbridge , 1950, 1952) in sea level, leaving extensive areas of coral limestone reef rock above water. Remnants of these form much of the consolidated part of most of the islets on present-day atolls, the rest of it having eroded away since exposure took place.

The geology of the islets, themselves, may be treated in greater detail as these structures are largely made up of the sediments to be discussed in the present paper.

General features of islets

All the northern Marshall Atolls have some dry land in the form small islets (pls. 1, 2) scattered along the reef flats (pls. 6, 8). These range from tiny deposits of sand and gravel (pl.10) almost awash at high tide to flat expanses as much as several miles long and almost half a mile wide. Not counted as islets are the rubble tracts (pl. 9) and storm-cast boulders lying on the reef flat (pl. 5D), though some of them may be exposed even at high water. The islets are essentially portions of the reef which lie above the general level of the reef flat. The materials are the same and there is no real difference except that they are exposed above sea level.

The surface of most islets lies between 4 and 10 feet above mean tide level but practically no accurate measurements of heights are available, nor have all the islets in the northern Marshall Islands been visited. Areas denuded by storms may lie close to high-tide level or even lower. Some islets have central depressions with bottoms at or slightly above high-tide level. Dunes, beach ridges, and boulder ridges may rise 6 to 12 feet or rarely even as much as 25 feet or more above mean tide level. A boulder-capped ridge on the south coast of Lae Islet has an altitude of about 18 feet. The highest altitude in the Marshall Islands is believed to be a beach or dune ridge on the lagoon side of Labinwor Islet, Likiep, on the leeward side of the atoll. Some parts of this ridge are more than 25 feet above mean sea level.

The islets may be regarded as ephemeral from a geological standpoint. This is shown by such evidences as ancient shorelines, indicated by beachrock, which do not coincide with the outlines of present islets, striking differences between outlines observed at present from those on maps of early surveys, and the relatively youthful character of the vegetation on some islets. That they are reasonably stable from a human standpoint however, is shown by the fact that a distinctive human population has occupied them for many generations; many islets show a well-developed vegetation, as well as populations of land animals, some of the latter unknown anywhere else.

Types of islets

Examination of a large number of islets shows that they are of three principal kinds: (a) those having a remnant of emerged reef rock, a mass of reef rock not yet eroded away, as a core; (b) those that are simply an accumulation of limestone detritus on the present reef flat; and (c) islets within lagoons. Type (a) islets are the result of a general lowering of sea level in relation to the reefs. This lowering of sea level is considered to have started several thousand years ago. Type (b) islets can be observed at present in all stages of formation in the northern Marshall Islands (pls. 9, 10). The three types and variants of them will be discussed separately, as they differ in some important respects. Types (a) and (b) are illustrated in figures 3 and 4.

Islets with a remnant of emerged reef rock as a core

By far the greater number of islets on atolls in the northern Marshall Islands are essentially platforms of reef breccia or conglomerate standing above the present reef-flat surface, with associated accumulations of sand, gravel, and larger debris. Most windward islets are of this type, as well as those on south reefs. This type of islet (fig. 3) may be readily identified by the presence of a rock platform (pls. 11-13) above high-tide level, protruding from beneath the sandy or gravelly vegetation-covered part of the seaward side of the islet. The platform may extend beneath the loose material of the islet for as much as a third or even two-thirds the distance to the lagoon beach. More rarely it may extend all the way and protrude from under the sand at the top of the lagoon beach (pls. 11B, 12C). On the seaward sides of windward islets the platform may be of considerable extent (pl. 2A). It presents a rough pitted surface, blackened by the growth of microscopic algae. The rock of which it is composed is generally a highly consolidated reef conglomerate or breccia of unsorted, often very angular fragments, case-hardened by exposure to air. The highest rock surface observed, excepting the remnants of Bwokwla (Bokla) islet, Taongi (Pokak), was about 5 1/2 feet above mean low tide. Others were from 1 to 2 or more feet lower, having probably been eroded by slow solution by rain water. The pitting of these surfaces shows that this solution process is constantly taking place (pls. 14-16).

The suggestion has been made that some islets apparently of this type may really belong to the second type, the platform being simulated by subaerially consolidated sediments. This possibility is hard to eliminate unless reef material in growth position is found. It is by no means certain that such consolidation does actually take place under atoll conditions, but it is possible. Petrographic studies of the type of cementation and recrystallization involved might yield dependable criteria for distinguishing subaerial from intertidal and submarine consolidation, but we know of no such studies on atolls as yet. At present, degree of consolidation, indications of planation surfaces, and fossils of intertidal organisms in their characteristic growth habitats and positions are the best available criteria for concluding that the apparent platforms are of formerly submerged rock.

The edge of this platform may be more or less abrupt and ledgelike or it may slope. Commonly a ramplike slope of irregularly eroded rock, a few to many yards wide, extends from the edge or base of the ledge down to the reef flat just above low-tide level. There may be a transitional area of irregular or roughened rock slightly higher than the reef flat. The ramplike slope has been termed the erosion ramp (pls. 11A, 14A, B, D, 15, 16, 17B, D), as it is here that the active erosion of this elevated reef rock is taking place. Comparable erosion ramps may also be cut in beach rock (pl. 14A).

Several processes were observed which contribute to this erosion. Solution, by rain water and possibly by sea water also, is a factor, as is shown by the prevalence of the pitted surfaces characteristic of limestone erosion. The outlines of the animal skeletons of which the rock is composed are often left in relief. Solution basins (pls. 15, 17D, 20C) from about an inch to as much as a foot deep, with straight or slightly undercut sides, are commonly seen. An abundance of small mollusks (such as *Nerita*, *Littorina*) and other animals that feed on algae in the surface of the rock undoubtedly contribute to abrasion of the surface in this zone. Abrasion by rolling back and forth, or swirling in pot-holes, of gravel, pebbles, and even larger rocks by waves leaves noticeable effects (pl. 19C, D). A conspicuous process is the spalling off of slabs of rock (pl. 16) from a foot to as much as 6 feet across, presumably due to sudden chilling of sun-heated rock by the rise of water with the tide. Spall planes cut through coral fragments and interstitial material alike, leaving smooth surfaces (pl. 16B). The constantly moving water of even small lagoon waves tends to cut away weaker beds and areas in the limestone, often undermining stronger rock, which then may collapse (pl. 14A, B), contributing large angular fragments to the loose rubble mass lying on the reef flat or erosion ramp. Just how important this process is and just how much of it occurs in normal weather and how much in storms are hard to estimate, but a combination of storm and normal erosion of this sort unquestionably accounts for the removal of a sizeable volume of material. Much of this material may be identified in the rubble deposits around the peripheries of the islets. What is probably the most important process of all is the weakening and crumbling of rock in the intertidal zone that result from the activities of boring organisms, especially one or more species of sipunculid worms. In many localities a narrow band of rock on the erosion ramp was seen to be riddled with the burrows of these worms, usually with the animals still inside. How the sipunculids accomplish the boring is not known, as they do not have boring mouthparts. They may, of course, dissolve away the limestone by acid body secretions. Other worms, mollusks, echinoids, sponges, and blue-green algae were also observed to contribute to the disintegration and erosion of limestone by boring in this intertidal belt.

The total effect of all these processes is the removal of an enormous amount of rock, resulting in planation down to low-tide level, and the production of large quantities of sediments. The extent of present-day reef flats (pls. 1, 2, 6, 8, 9), frequently half a mile to a mile wide, is a measure of the planation that is thought to have taken place since the fall of sea level which happened several thousand years ago.

Locally, the erosion ramp may be covered by beaches (pls. 17, 18) of sand, gravel, or cobbles, or the beaches may be restricted to an area above the edge of the protruding rock platform. The ramp itself is commonly found on the seaward side of the islets and frequently extends along the channels between islets, but has only rarely been observed on the lagoon side by us. Deposits of any sort of material such as sand, gravel, boulders, unsorted rubble, or even large slabs (pl. 20D) may be piled on and around the hard rock core of the islet. They may even cover it completely, in which case the islet may be mistaken for type (b). The lagoon side of type (a) islets is usually built of sand or small gravel (pls. 17A, 18). Often there are evidences of successive deposits of sand in the form of beaches or ridges which have been added lagoonward.

There is a tendency for islets of this type on windward reefs to be strongly convex on the seaward side and somewhat concave on the lagoon side, with prominent angles on the lagoon corners. The islets may be widest in either direction but those elongated perpendicular to the trend of the reef have a tendency to broaden along the lagoon beach so that they are roughly T-shaped, with a narrow rock platform extending seaward from a bar of sand along the lagoon shore. Sand horns (fig. 3, pl. 2B) and sand lobes, spits extending from the inner corners, are common on islets on windward reefs. Sand aprons are broad deposits of material in shallow water just inside the reef, especially windward reefs.

Islets formed of accumulations of loose material on reef flats

Accumulation of sand, gravel, or unsorted material on the surface of the reef may result from any one of several causes or combinations of them: (1) Storms may deposit tracts of large boulders (pl. 9) on the reef, which are too heavy to be removed by ordinary wave action; later, smaller material may be piled around and among these; (2) The reef may be so wide that the force of normal waves is insufficient to carry loose material completely across and into the lagoon, and it may pile up on the reef; (3) The same thing may result from lagoon waves neutralizing sea waves, causing them to drop any loose materials they are carrying. Bars (pl. 10) formed in any of the above ways may become large enough to resist moderate storm waves which may then pile the material up above the high-tide level, or wind may also pile it up. These bars may become partially consolidated into beachrock (pls. 19, 20), which may survive even severe storms and serve to catch more loose material. Surfaces above high-tide level soon become colonized by plants (pl. 27B) the resulting vegetation further stabilizing the islets.

Regardless of how the loose material has become stabilized, these islets are essentially only piles of detritus on the flat surface of the reef. The core may or may not be of large boulders or consolidated material. Some islets which appear to be of this type may actually be of type (a), described above, but with the entire platform or remnants of it completely buried by loose material (fig. 4B).

Detrital islets may form on any part of the periphery of an atoll but are usually found on wider parts of the reef. Practically all islets on western reefs, many of those on southern reefs, and some on windward reefs may be so formed. They are of all sizes and shapes. Those on widened corners of atolls tend to be triangular or prolonged in the direction of the angle of the reef. Those on straight or gently curving reefs tend to be elongate in the direction of the length of the reef. Small bars tend to be crescent shaped, with the horns of the crescent downwind, or, rarely, concave toward the wind, but with the tips of the horns recurved in a downwind direction. Such small bars are frequently high around the periphery and depressed in the middle. Finer material is often removed from the surface by wind or waves, leaving a layer of loose gravel.

Islets of this sort, at least while small, are more vulnerable to the force of typhoons and lesser storms than those with a hard rock core. Storm waves, if severe enough, can move enormous quantities of loose material, even chunks. They may, on the other hand, add material either from the outer margin of the reef or from nearby islets, or occasionally, perhaps, from sand aprons in the lagoon.

Islets within the lagoon

In addition to the two main types a few islets exist within the lagoons, especially just inside the passes. Most of these (perhaps all) are composed entirely of sand accumulated on patch reefs at or just below the level of the lagoon water. The sand is piled up in low hillocks or dunes and may be well vegetated. Such islets occur in the lagoons of Likiep, Kwajalein, Wotje, and Eniwetok, and perhaps one on Rongelap would be in this class. Eniwetak islet in Kwajalein Lagoon, was the only one of this sort examined closely, and that during a very short visit only. It consists of a relatively small flat area of sand 6 or 8 feet above lagoon level, with steep sides, and with one corner at a lower level forming a terrace. It is bordered, at least on one side, by a fringing reef.

The origin of these lagoon islets is obscure. They may be simply of sand deposited on the reefs by wind, but this does not explain their being usually located just inside passes. It has been suggested (K. O. Emery, oral communication) that the sand may have been deposited by currents prior to the fall of sea level; if so, these islets are a special case of type (a).

Shores

Shores (the strips of land between mean low tide and the high-water mark of ordinary storm waves), may be divided into those predominantly of loose or unconsolidated materials, called beaches (pls. 17, 18), and those of hard or consolidated materials or rock. These are not sharply separated, as loose materials may be scattered or spread in various manners over rock shores, rock may be variously exposed by erosion of beaches, and beaches may even become consolidated to form beachrock. Generally, the two types and obvious combinations of them may be easily distinguished.

Beaches

Beaches are, within certain limits, continuously and locally variable and may be classified only arbitrarily. Furthermore, the same beach may change completely even during the course of a single storm. Therefore, it is possible to speak only in generalities and in terms of what may be reasonably expected in certain situations. As to topographic position, beaches are readily divided into tidal and storm beaches (pls. 11B, 17A), the tidal beaches lying between low-tide level and extreme high-tide mark, storm beaches lying above high tide. In texture both of these may be sand, pebble, cobble, or boulder beaches, any combination of these, or intermediate between them. Beaches commonly (but not universally) slope from the land toward the water, the nature and steepness of the slope being determined by the nature of the detrital material, the substratum on which it is lying, and a combination of all the forces of waves, currents, and winds which have acted upon it. The analysis of these forces is extremely difficult, formulation of it is not yet in a very advanced state and our data are not adequate for such detailed consideration.

Beaches exposed to the direct force of waves generated by the trade winds, or of frequent southerly storm waves and swells are generally much steeper than those on more sheltered coasts. Lagoon beaches generally are less steep than seaward beaches, except on leeward sides of large lagoons where strong waves may be generated. The slope is usually in the form of one or two shallow concave curves with a break at high-tide level. High sand or gravel beaches frequently have a sand terrace or berm (pl. 17A) at high-tide level between the storm and tidal parts of the beach.

Sand beaches (pl. 18A) may be found in any situation on either windward or leeward islets. However, they tend to be both more common and more extensive on lagoon shores than on seaward shores. On the lagoon shores of windward islets the sand is usually finer than on those of leeward islets, especially southern ones, where the beaches are frequently of gravel rather than sand. The sand particles of beaches on windward islets are generally much more angular than those of leeward ones, where they are worn and rounded. On islets with an exposed platform of rock there is frequently a storm beach above the rock platform. Where no rock platform is exposed, the beach commonly extends from the vegetation down to the reef flat, or erosion ramp, or on lagoon beaches down to the sand apron with which it merges. If there is a beachrock formation along the shore, there is more often than not a storm beach behind it, either continuous with the top of the beachrock or separated from it by a low escarpment or cuesta.

Pebble beaches (pls. 17A, 18B) are common along windward shores of windward islets. They also occur along the channel sides of all islets except those on the western reefs that consist mostly of sand; they are especially common on the lagoon shores of leeward islets on the south reefs. In texture pebble beaches vary from fine to coarse, where they merge with cobble or boulder beaches, and the particles may be well sorted or more rarely mixed in any proportion of sizes.

Sand and gravel beaches are commonly white to pinkish in color, particularly where the material is frequently disturbed and worked over by wind and waves. Where beaches are undisturbed for long periods of time, the color of storm beaches becomes progressively more grayish or even blackish, from the growth of microscopic algae on the upper surfaces of the particles.

Cobble or boulder beaches (pls. 13A, 17C, D) are commonly associated with storm deposits of coarse material (boulder or cobble ridges), hence are more frequently found on southern seaward shores; they may, however, be found in any position, though rarely on western leeward islets. The size of the fragments of rock varies but may be a foot or more in diameter. Cobble size, from 3 to 10 inches, is more common. At times a combination of a storm beach of boulders or cobbles with a tidal beach of sand or pebbles, or the reverse, may be encountered; more frequently both tidal and storm beaches are of material of similar texture. Generally, the smaller sizes tend to be less angular than large boulders, presumably because small pieces are more frequently rolled around. This, however, is by no means always so. Beaches of such coarse material occur rather rarely on lagoon shores except adjacent to deep passes on south reefs. Even on Taongi (Pokak) where there is a short beach ridge of cobbles along the lagoon shore of Sibylla islet, the beach below it is of sand.

Rock shores

Rock shores are of two types, those of slanting beds of beachrock (pls. 19A, B, 20A, B) and those of reef rock (pls. 11A, 12) in which the bedding is obscure or horizontal.

Beachrock shores (pls. 19A, B, 20A, B) may slope at the angle of the bedding planes, ranging from 5° to more than 30°, or may be truncated by erosion to a much gentler slope than the dip of the beds. Frequently, where there is a wide series of beds, these may be represented by a series of sharp parallel ridges at or just above high-tide level. Where beachrock is between tides it may be smooth from abrasion by wave-rolled gravel, pitted with large potholes (pl. 20C) and solution basins, or it may be cracked into large slabs or blocks (pls. 14C, 20D). These, as on the lagoon shore of Yeldo (Enejelto) islet on the east side of Wotho Atoll, may be thrown up into an irregular windrow on the storm beach above (pl. 20D). Near and especially above high-tide level the surface may be extremely rough and pitted (pl. 14A, B), almost honeycombed, from weathering by rainwater. Here, also, the surface is likely to be very dark or almost black from algal growth. To the casual observer these jagged blackened surfaces may suggest volcanic rock, which is not exposed on atolls.

Reefrock shores (pls. 11A, 12) are of two principal types, those where a platform of elevated reef protrudes from beneath the vegetation well above high-tide level, ending either in a ledge or an erosion ramp; and those where the rock has been eroded down to high-tide level or below. The latter type is commonly rather rough and may end in a low cliff if on the lagoon side, or merge into an erosion ramp on other sides of an islet. Both these types may commonly be partly covered by beach deposits. On Bwokwla islet, Taongi (Pokak) Atoll, the lagoon shore is a platform about 1 foot above high-tide level and is conspicuously undercut. An approach toward this condition may be seen on other lagoon shores of south reefs. Where a similar emerged platform protrudes onto a reef flat there always seems to be some development of an erosion ramp (pls. 11A, 15, 16). This may be broad, as much as 100 feet wide, and gently sloping, or as narrow as 3 to 4 feet and steep. Steep clifflike shores may also be found lining inter-islet channels where the islets are very close together, but still separated by water. Such a situation is to be seen between Anenlik (Enelik) and Jabwe islets, Ailuk Atoll.

Ledgelike shores frequently have their erosion ramps covered or partly covered by accumulations of coarse rubble. This is commonly in the nature of a mantle resting on the underlying rock, it is rarely banked up in the form of a beach. This may be seen most often near the seaward ends of passages between islets. The surface of the ramp is usually somewhat rough and pitted, sometimes extremely so. In other examples the roughness may be moderated by abrasion from wave-rolled gravel, as on some beachrock shores. The transition to the relatively smooth reef flat surface may be abrupt or gradual, in places marked by minor corrugations perpendicular to the waves. A good example of these corrugations is shown by Schlanger and Brookhart (1955, pl. 1). Elsewhere the edge of the ramp is irregular with many low spurs and reentrants.

Beachrock

A feature of atoll islets so common and conspicuous as to deserve special mention consists of narrow elongate beds of consolidated sand, gravel, or even larger material, dipping at the angle of inclination of a beach surface (pls. 19, 20). Such beds may consist of a single layer a few inches thick, or more commonly many such layers superimposed and dipping at the same angle. Owing to the small lateral extent of the single beds the actual vertical thickness or depth of such a series is very small. The total vertical dimension of the series is not more than the distance between mean high and low tides, except where such beds persist from an earlier higher sea level. In such cases, they may extend 1 or 2, or even 4 feet above mean high tide, and if recent beds have been added to the series, down to low-tide level. A continuous series of these beds may reach an extreme width of 20 yards or even more, but usually such a series is not more than 3 or 4 yards wide. The length is quite varied but may be as much as hundreds of yards.

Beachrock apparently forms beneath the surface of beaches and when first exposed by wind or wave action may be very weakly consolidated; the particles are cemented by a coating of aragonite needles. Exposure to air tends to harden the rock so that it may persist for a long period, as is shown by ancient beds now above high-tide level that must have been formed while sea level was higher than at present. This is undoubtedly a manifestation of the general phenomenon of "case-hardening" of exposed limestone, apparently due to recrystallization of calcite, which shows in some thin-sections of old, hardened beachrock.

Long strips of beachrock commonly occur around the peripheries of islets, usually sloping away from the islet, toward either lagoon or sea, in the manner of beaches of loose sand. However, locally the dip may be just the opposite of what would be expected, suggesting that the islet may not have always been in its present position. Such displacement of islets is also indicated by strips of beachrock found in the interior of islets and in various positions on otherwise denuded reef flats, between islets, or away from them altogether. On some reefs, such as that extending westward from Utirik Islet, Utirik Atoll, there may be a number of parallel series of beachrock beds, the seaward ones dipping seaward, those along the lagoon dipping lagoonward. It is thought that a typhoon may have removed most of the loose material from the reef flat here, leaving beachrock marking former shorelines of the islet. In places, especially near reef angles and the corners of islets, extremely complicated arrangements of beachrock may be exposed, indicating many shifts in former shorelines. A conspicuous example may be seen on the eastern point of Likiep Islet, Likiep Atoll.

Marginal ridges

Ridges (pls. 21, 22A, B) of unconsolidated limestone detritus are common just inside the margins of islets, especially along the seaward sides. The material varies in texture from fine sand, less than 0.5 mm in diameter, to cobbles and even boulders. The ridges may be interrupted or may extend continuously around an islet. Small islets are especially likely to have ridges all around them. The ridges are likely to be highest on the seaward side and the highest ones are on south shores.

These ridges may be normal beach ridges, piled up by waves, or by waves with the help of wind; they may be enormous masses of cobbles and boulders probably cast up by typhoons; or they may be dunes resulting from wind-blown sand caught by vegetation.

Beach ridges are the most common, existing at the tops of most beaches at least to some extent. They are commonly broad, low, and rounded in profile, seldom more than 2 to 4 feet above the general level of the islet surface. Where recent and not yet vegetated they may be narrow with sharp tops. Frequently they are double, the front crest sharp and narrow, the back one rounded and broad. In texture they generally correspond somewhat to the beaches that are in front of them, being sandy along most lagoon slopes except those on south reefs and frequently so along seaward slopes of windward islets. Along the lagoon side of islets on the south reef they tend to be of gravel, which often changes from coarse to fine from east to west along any particular islet, ending in sand at the west end. Gravel ridges as well as sand ridges may also be found along the seaward south shores of the islets where these are not occupied by storm deposits. The gravel is commonly rather rounded but may be angular in some situations. Many small sand and gravel bars are simple peripheral ridges surrounding bowl-shaped depressions.

The most conspicuous surface features of atoll islets are the enormous boulder ridges (pl. 22A, B), often termed "boulder ramparts", which occur on some islets of most atolls. These are beach ridges formed of large-size material. They are somewhat randomly distributed, being known from coasts facing in almost all directions, and from lagoon as well as seaward sides. They are, however, far more frequent along the seaward coasts of islets on the south reefs, and least frequent on lagoon coasts and on islets on west reefs. The texture of the material ranges up through cobble to boulder sizes (pl. 22). Different segments and layers in the same ridge often may be of very different average size and have abrupt boundaries between them. The highest known boulder ridge in the northern Marshall Islands is on the south coast of Lae Islet, Lae Atoll. It is about 18 feet high, with the upper several feet composed of huge boulders, a foot or more in diameter. Generally the size range of the material is much smaller than this and the height is between 5 and 10 feet. The rocks are frequently very angular and sharp and the upper layers may have relatively little finer material in the interstices. The profile of the ridges varies from narrow, with the seaward side rather steep, to broad, as much as 100 yards wide, with very gradual slopes. Where the ridge is wide a secondary ridge may frequently develop at its seaward margin, this one much sharper and with a steep seaward slope.

There is no sharp distinction between the boulder ridges and ordinary beach ridges. Their occurrence in a more or less random distribution, with a predominance on south reefs, and the energy requirements for moving and piling up such large fragments suggest that boulder ridges may be thrown up by typhoons, whereas ordinary beach ridges are probably formed by milder storms or ordinary high waves in rough weather.

Both beach ridges and boulder ridges in some situations occur in series, with more recent ones partly superimposed on the older, arranged from older to younger in either a seaward or lagoonward direction, starting from the interior of the islet. This arrangement is thought to result from successive heavy storms, each depositing a great mass of material. The vegetation on such a series may be observed to be more mature on the inner ridges, and the rocks may be more blackened. Islets may be enlarged by such deposition, especially on the lagoon side, but only where shallow water, a reef flat, or a sand apron exists along the original shore. Often the lagoonward third or more of an islet seems to have been built in this way, usually of smaller size material than that found in seaward beach ridges or boulder ridges.

Dunes, likewise, may be found in almost any situation, but they are most common along lagoon shores, especially on islets on west reefs and the west ends of those on south reefs. They are also found on the rare islets inside the lagoons. The dunes in the northern Marshall Islands are all small and are mostly stabilized by vegetation. It is likely that the vegetation is principally responsible for their formation by stopping the wind-driven sand and causing it to pile up among bushes and trees. The presence of pebbles and even some cobbles and boulders in many of these dune ridges shows that storm waves have frequently had a part in their construction.

Interiors of islets

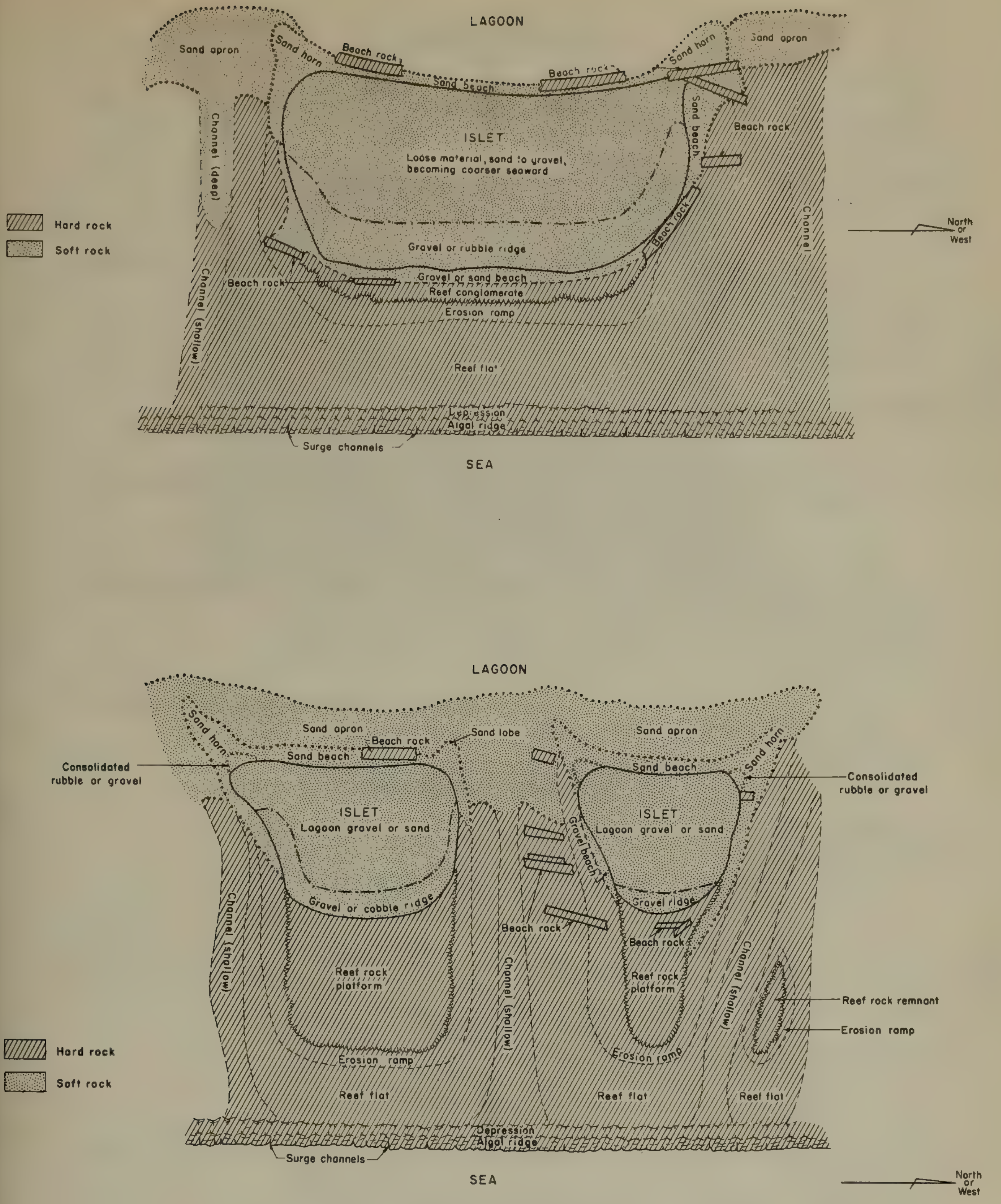
Inside the marginal ridge an islet may have little relief. It commonly shows an extremely slight slope upward from the lagoon side, with a surface of sand near the lagoon, becoming gradually coarser toward the sea. Boulders and blocks of reef rock, many of enormous size, are scattered over the surface of many islets inward from the seaward side to as much as 200 yards, or even more. These are more common where there is a well-developed boulder ridge along the seaward coast. The only apparent explanation is that they were carried inland by enormous typhoon waves. Their presence vividly illustrates the power of such waves, as the largest boulders must weigh tons. Occasionally there are areas, termed block fields, which are thickly covered with such boulders and large rubble, even to a depth of 1 to 4 feet. The narrow seaward parts of some windward islets may be composed entirely of coarse, loose rubble. The seaward sides of islets on south reefs may be covered by several feet of boulders and blocks, 6 inches to 3 feet in diameter, extending 200 feet or more back from the beach. This type of deposit usually but not always assumes the form of a broad low ridge, as described above under boulder ridges. Holes, loose blocks, and a tangle of vines may make footing here precarious.

Other topographic features may be found locally. Broad central depressions may occur. On Lado Islet, Likiep Atoll, there are at least two such broad depressions parallel with the long axis of the islet. On long islets there may be two different types of transverse depressions. One results from the filling in of the gap between two islets, uniting them into one, usually with some indication of the former separation in the form of an inward scallop of the seaward beach. The depression is commonly very gradual and slight. The other type apparently results from partial breaching of an islet by typhoon waves, which sweep the loose material into sea or lagoon. This type of depression is likely to be more abrupt, with sand, rock, or coarse rubble on the bottom. The appearance of a reasonably recent scour of this type may resemble that of a dry stream bed, though of course there are no streams on these islets. The inner ends of both these types of transverse depressions are often filled by a lagoon beach ridge of gravel or sand. Broad flat areas at lower levels than that of the rest of islets are usually either recently filled by wind or storm deposits, or are areas scoured by typhoon waves.

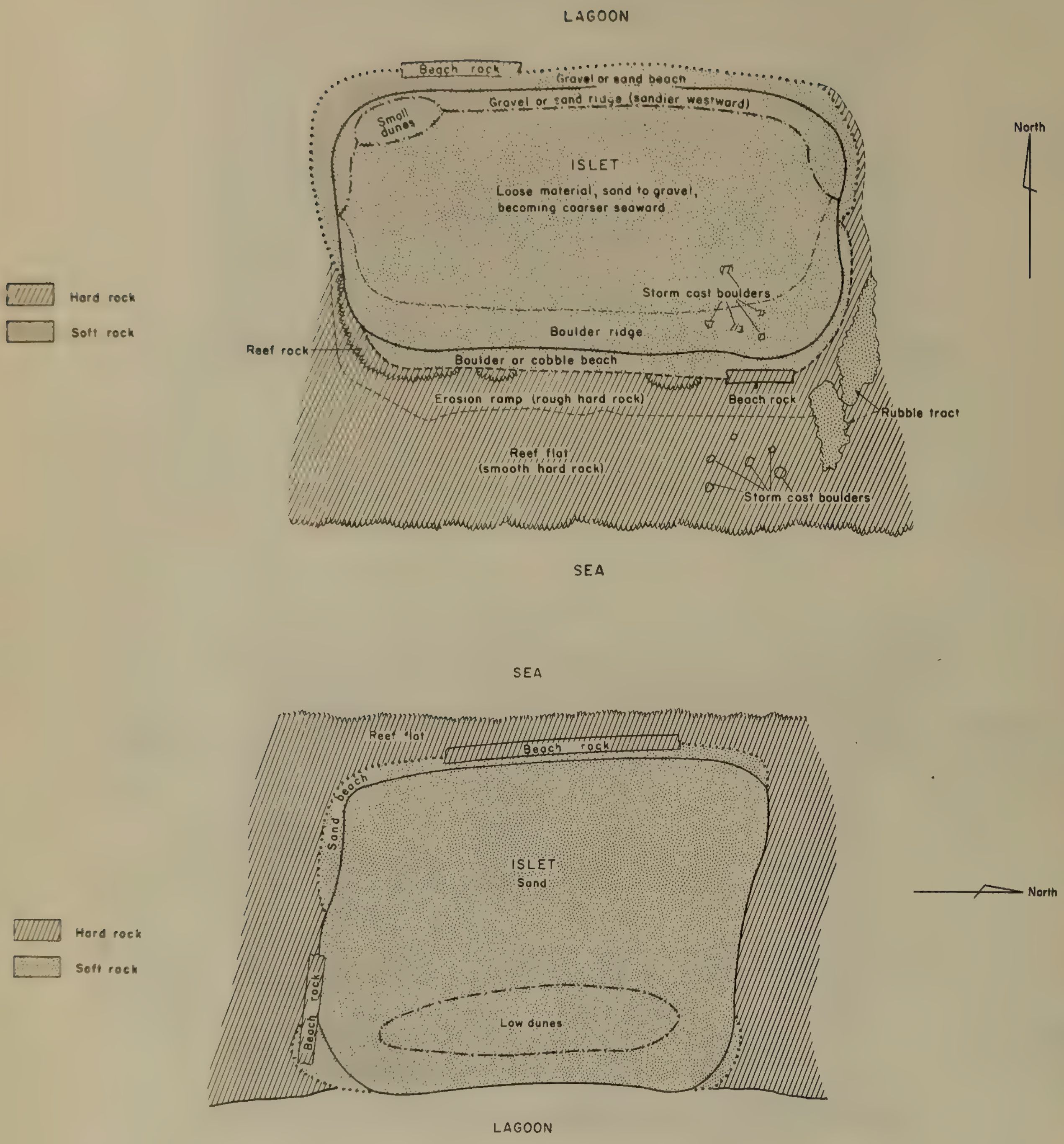
More abrupt, smaller, or irregularly winding depressions, from pond-like to trench-like, 3 to 6 feet deep, surrounded by piles of excavated sand and gravel, and usually with mucky soil in the bottom, are ancient taro pits dug by the inhabitants but abandoned many years ago. They are usually found near the centers of large islets or inward toward the lagoon. They are rarely found on atolls north of Ailuk. They are conspicuous on Wotho and Lae. Very rarely, small depressions are found containing tiny mangrove swamps. One such is found at the south end of Pigowak (Bekrak) Islet, Utirik Atoll, another on Jeltonet (Jeltoniej) Islet, Likiep Atoll.

Islets composed, entirely or in their lagoonward parts, of successive beach ridges have a topography of alternate ridges and furrows parallel with the lagoon margin. At places, as near the north end of Taka Islet, Taka Atoll, there is what appears to be a storm deposit of small sharp rubble rising slightly above a general surface of sand or gravel, well inward from the beach. This may be the result of growth of the islet subsequent to deposition of the rubble.

In the interior of a number of islets, such as Utirik Islet, and several of those on Wotho Atoll, are rounded mounds, a few yards in diameter, of small sharp coral fragments. These mounds may rise 2 to 4 feet above the general level of the interior of the islet. There is generally little or no fine material in the interstices, at least in the surface layers. The origin of these mounds is not clear but they may result from the pushing up of rubble by the roots of trees, possibly accentuated by the blowing down of trees by storms. Stages in this process were observed on the islets of Wotho Atoll. They differ, however, from the tree-fall mounds observed in continental forests in that they commonly have no hollow alongside, of the sort regarded as characteristic of such features. It may be that there is some other explanation, entirely, for them.


LAGOON
Sand apron
Sand horn
Beach rock
Sand beach
Beach rock
Sand horn
Sand apron
Sand beach
Beach rock
Channel (deep)
ISLET
Loose material, sand to gravel, becoming coarser seaward
Hard rock
Soft rock
Channel
North or West
Gravel or rubble ridge
Beach rock
Beach rock
Gravel or sand beach
Reef conglomerate
Erosion ramp
Channel (shallow)
Reef flat
Depression
Algal ridge
Surge channels
SEA
LAGOON
Sand horn
Sand apron
Beach rock
Sand lobe
Sand apron
Sand beach
Sand beach
Sand horn
Consolidated rubble or gravel
Consolidated rubble or gravel
ISLET
Lagoon gravel or sand
ISLET
Lagoon gravel or sand
Gravel beach
Gravel or cobble ridge
Gravel ridge
Beach rock
Beach rock
Channel (shallow)
Reef rock platform
Channel (shallow)
Reef rock platform
Channel (shallow)
Reef rock remnant
Erosion ramp
Hard rock
Soft rock
Erosion ramp
Erosion ramp
Reef flat
Reef flat
Reef flat
Depression
Algal ridge
Surge channels
SEA
North or West

3. Diagrams of typical windward islets showing position of surface features. A, single islet on reef flat; B, two small adjacent islets on reef flat.


LAGOON
Beach rock
Gravel or sand beach
Gravel or sand ridge (sandier westward)
Small dunes
North
ISLET
Loose material, sand to gravel, becoming coarser seaward
Hard rock
Soft rock
Storm cast boulders
Boulder ridge
Reef rock
Boulder or cobble beach
Erosion ramp (rough hard rock)
Beach rock
Rubble tract
Reef flat
(smooth hard rock)
Storm cast boulders
SEA
SEA
Reef flat
Beach rock
Sand beach
ISLET
Sand
North
Hard rock
Soft rock
Beach rock
Low dunes
LAGOON

4. Diagrams of typical leeward islets showing position of surface features. A, islet on south reef; B, islet on west reef.

Legends of plates

Plate 1. Aerial views of Lae and Ailuk Atolls.
- A. Lae Atoll from the air, viewed from north. Photographed by D. B. Doan.
- B. Ailuk Atoll, east reef with islets, from the air, viewed from south. Photograph by F. R. Fosberg.

Plate 2. Islets on reefs of Ailuk and Taka Atolls.
- A. Islets on east reef of Ailuk Atoll, viewed from west, showing denuded platform seaward of islet, remnants of platform in channel, rubble tracts in channel, and coconut plantations protected by crescent-shaped windbreak of native vegetation.
- B. Eluk islet, Taka Atoll, showing sand horns and beachrock.
  Photographs by F. R. Fosberg.

Plate 3. A, B. Corals growing in lagoon, on reef inside Rua and Ebbetyu (Ebeju) islets, Ujae Atoll, depth 1-3 meters. Photos by F. R. Fosberg.

Plate 4. A, B. Surge channel through algal ridge, windward reef, Wotho islet, Wotho Atoll. The reef here is composed of colonies of several species of the algal genus *Porolithon*. Photos by F. Stearns MacNeil.

Plate 5. Windward reef features.
- A, B, C. Algal ridge, windward reef opposite Lado islet, Likiep Atoll, composed mainly of several species of *Porolithon*. Photos by Fosberg.

- D. Moat or back-ridge trough behind algal ridge, windward reef opposite Lojjairok (South Loj) islet, Kwajalein Atoll. Reef-flat and storm-cast boulders to left in distance. Photos by MacNeil.

Plate 6. Details of reef flats.
- A. Detail of reef flat, at low tide, windward reef, Wotho islet, Wotho Atoll. Note small algal colonies and relatively smooth surface.
- B. Detail of reef flat, at low tide, leeward reef, southwest of Ailuk islet, Ailuk Atoll.
  Photos by MacNeil.

Plate 7. A, B. Outer margin of leeward reef and reef flat at low tide, southwest of Ailuk islet, Ailuk Atoll. Note absence of algal ridge and prevalence of corals. Photos by MacNeil.

Plate 8. Windward reef flat, Taka Atoll, near Lojrong (Lojiron) islet, at low tide, showing solution basins with raised rims. Photo by MacNeil.

Plate 9. Rubble tract on reef flat, windward reef, Ujelang Atoll. Photo by MacNeil.

Plate 10.
A. Crescent-shaped gravel bar on leeward reef east of Lotj (Loj) islet, Lae Atoll.
B. Seaward end of gravel bar, windward reef, Ujelang Atoll.
Photos by MacNeil.

Plate 11. Post-Pleistocene eroded reef platforms.
A. Post-Pleistocene reef platform with erosion ramp, Taka islet, Taka Atoll.
B. Lagoon beach, Taka islet, Taka Atoll, showing tidal beach, eroded post-Pleistocene reef platform, and storm beach.
Photos by MacNeil.

Plate 12. Exposure of post-Pleistocene reef platforms.
A. Ennimenetto islet, Ujelang Atoll.
B. Jabwe islet, Ailuk Atoll.
C. Lae islet, Lae Atoll, lagoon beach.
D. Lojjairok (South Loj) islet, Kwajalein Atoll.
Photos A, C, D by MacNeil; B by Fosberg.

Plate 13. A, B. Boulder beach and exposed post-Pleistocene rock platform with stack and perched boulder.
Photos by Fosberg.

Plate 14. Surfaces of erosion ramps.
A. Erosion ramp on Ulka (Ulika) islet, Ailuk Atoll, showing rough pitted surface and undercutting; storm beach in background.
B. Same, closeup, showing collapse of undercut limestone (width of foreground about 5 feet).
C. Beachrock on Yeldo (Enejelto) islet, Wotho Atoll, being undercut and quarried by waves (width of foreground about 8 feet).
D. Closeup of edge of erosion ramp, showing solution features, Ebbetyu (Ebeju) islet, Ujae Atoll.
Photos A, B, C by Fosberg; D by MacNeil.

Plate 15. Solution basins on erosion ramps.
A. Solution basins with overhanging rims, erosion ramp, Emejiwan (Enijwa) islet, Likiep Atoll. Photo by MacNeil.
B. Solution basins on erosion ramp, north end of Taka islet, Taka Atoll, showing chalky deposit in bottom. Photo by Fosberg.

Plate 16. Spalling off of erosion ramp surfaces.

A. Surface of erosion ramp, Erlie (Alle) islet, Ujae Atoll, showing spalled slab and spall plane. Photo by MacNeil.

B. Surface of erosion ramp north end of Taka islet, Taka Atoll, showing spall planes of different ages as indicated by different degrees of pitting and discoloration by algal growth. Area 2-3 square feet. Photo by Fosberg.

Plate 17. Gravel and boulder beaches.

A. Gravel beach on lagoon side of Bik islet, Ujae Atoll, showing terrace or berm.

B. Erosion ramp with small storm beach on left, Daisu(Raij) islet, Ujelang Atoll.

C. Boulder beach, Bock islet, Ujae Atoll.

D. Boulder beach, Ujae islet, Ujae Atoll, showing abraded erosion ramp.

Photos by MacNeil.

Plate 18. Sand and gravel beaches on lagoon side of islets.

A. Sand beach, lagoon side, Utirik islet, Utirik Atoll. Photo by Fosberg.

B. Gravel beach, lagoon side, Nelle islet, Ujelang Atoll. Photo by MacNeil.

Plate 19. Details of abraded beachrock.

A. Beachrock series on northwest corner of Emejiwan(Rikararu) islet, Likiep Atoll.

B. Beachrock cuesta at southwest corner of Emejiwan(Rikararu) islet, Likiep Atoll.

C. Abraded beachrock, Jemo island, showing abrasive agent.

D. Closeup of abraded beachrock on Jemo island, showing composition.

Photos A, B by MacNeil; C, D by Fosberg.

Plate 20. Details of beachrock.

A. Beachrock series, Rua islet, Ujae Atoll.

B. Beachrock showing anticline-like arrangement, dipping seaward (to right) and lagoonward (to left), Rua islet, Ujae Atoll.

C. Potholes in beachrock on lagoon beach, north end of Bokanaetok islet, Wotho Atoll.

D. Slabs of beachrock quarried by lagoon waves and piled up at top of beach, Yeldo (Enejelto) islet, Wotho Atoll.

Photos by Fosberg.

Plate 21. Beach ridges of pebbles and cobbles.

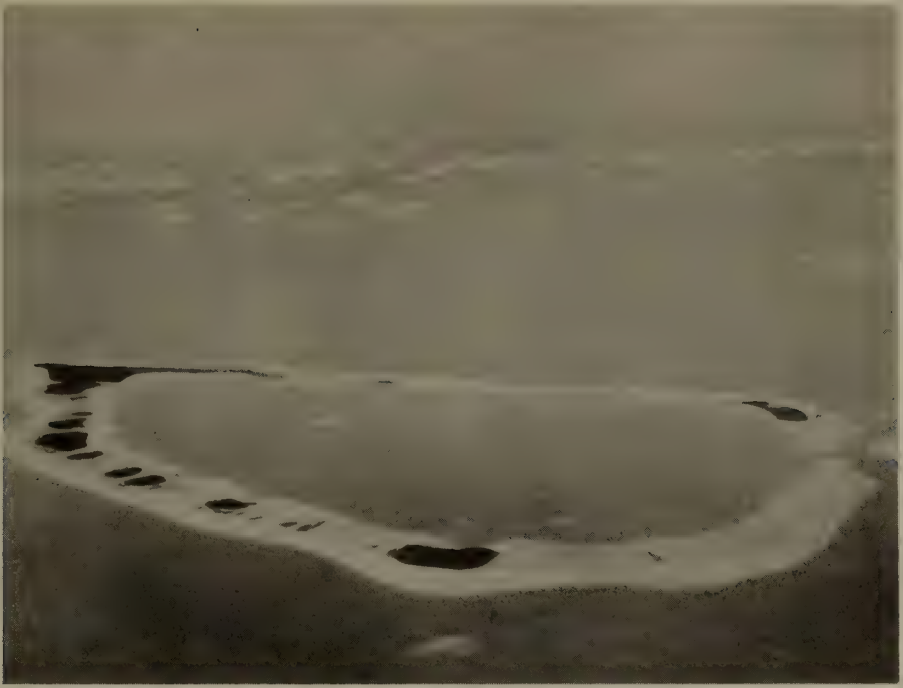
- A. Beach ridge of pebbles, Ailuk islet, Ailuk Atoll. Photo by MacNeil.
- B. Beach ridge of cobbles, Utirik islet, Utirik Atoll. Photo by Fosberg.

Plate 22. Details of boulder and cobble ridges and other coarse deposits.

- A. Boulder ridge, south side, Sibylla islet, Taongi (Pokak) Atoll.
- B. Details of mixture of boulders and cobbles, boulder ridge, Utirik islet, Utirik Atoll. Large boulder in lower right about 16 inches across.
- C. Details of coarse gravel, with tern (*Procelsterna caerulea*) nesting, beach ridge on small bar between Jabwelo (Jaliklik) and Almani islets, Bikar Atoll.
- D. Details of small gravel on flat, with young noddy tern (*Anous stolidus*), Daisu (Raij) islet, Ujelang Atoll.

Photos A, B, C by Fosberg; D by MacNeil.

Plate 1



A

B

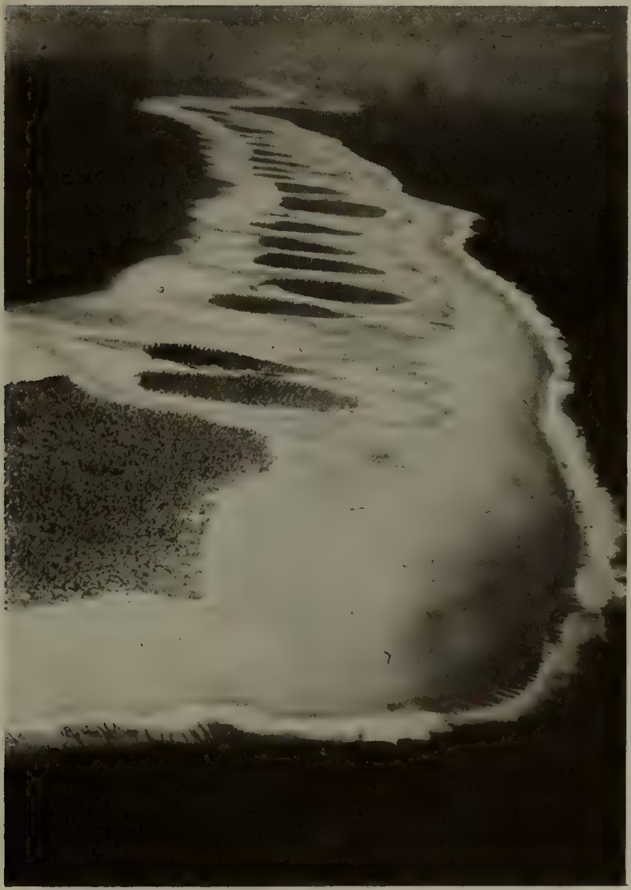


Plate 2

A

B

Plate 3

A

B

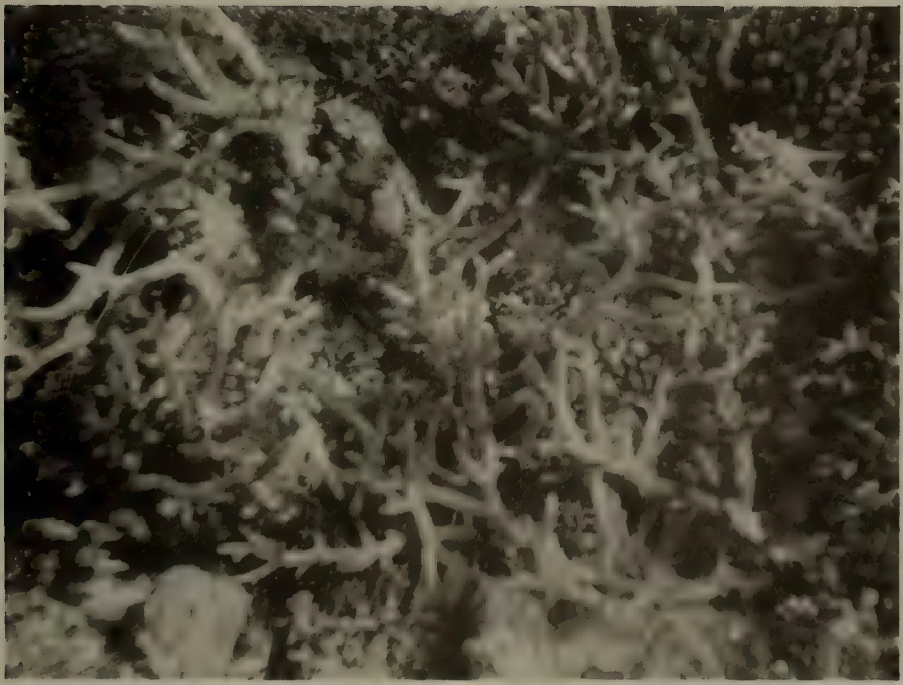


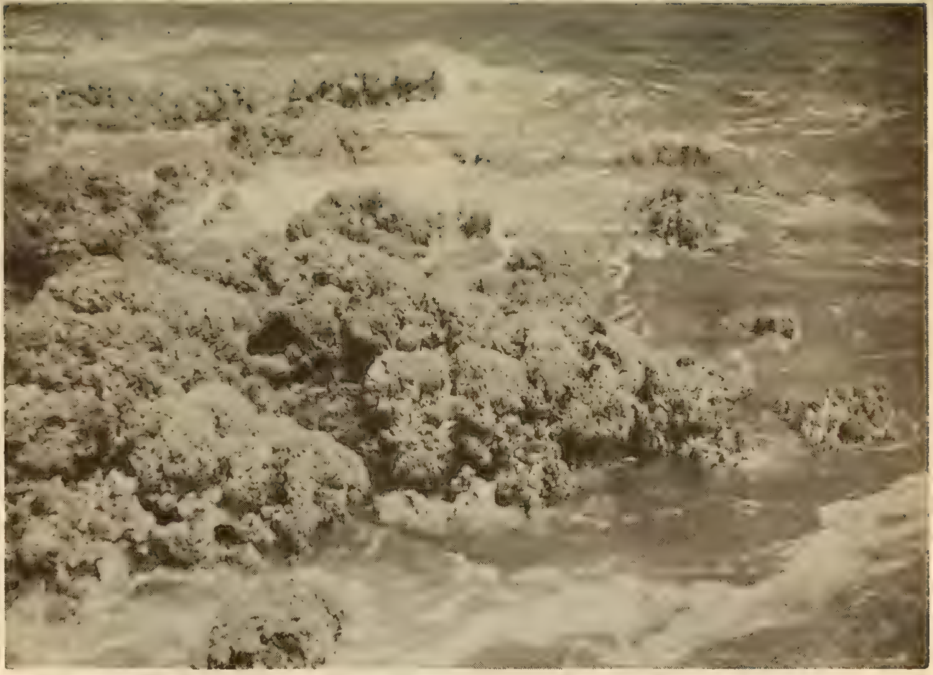
Plate 4

A

B

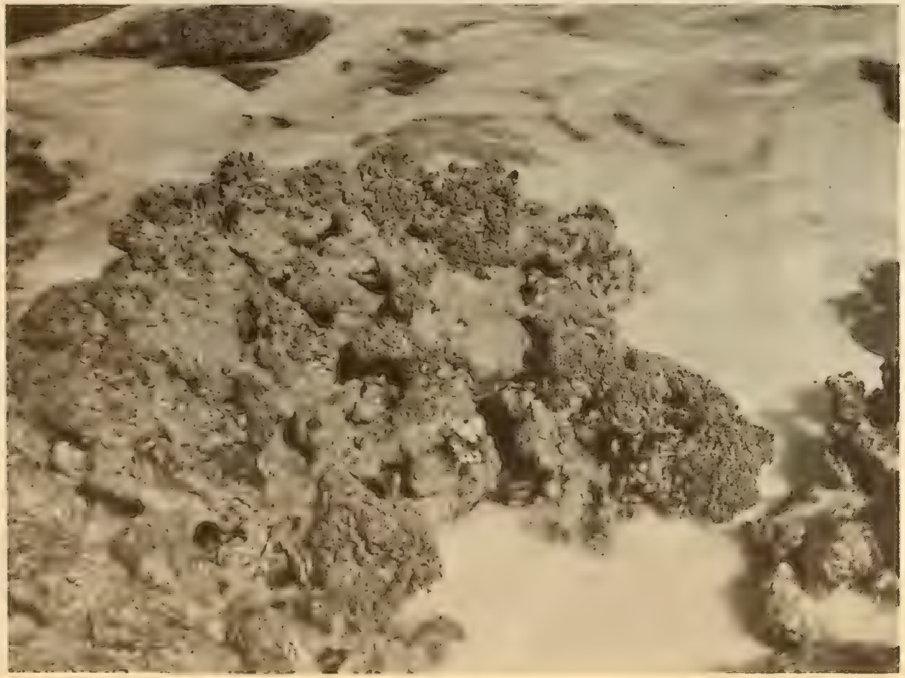
Plate 5

A



B

C



D

Plate 6

A

B

Plate 7

A

B

Plate 8

Plate 9

Plate 10

A

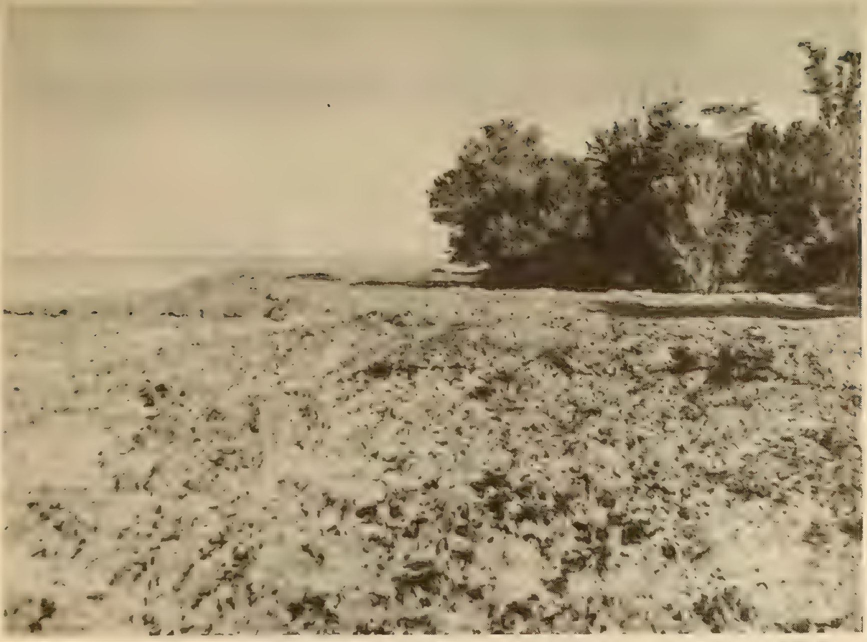
B

Plate 11

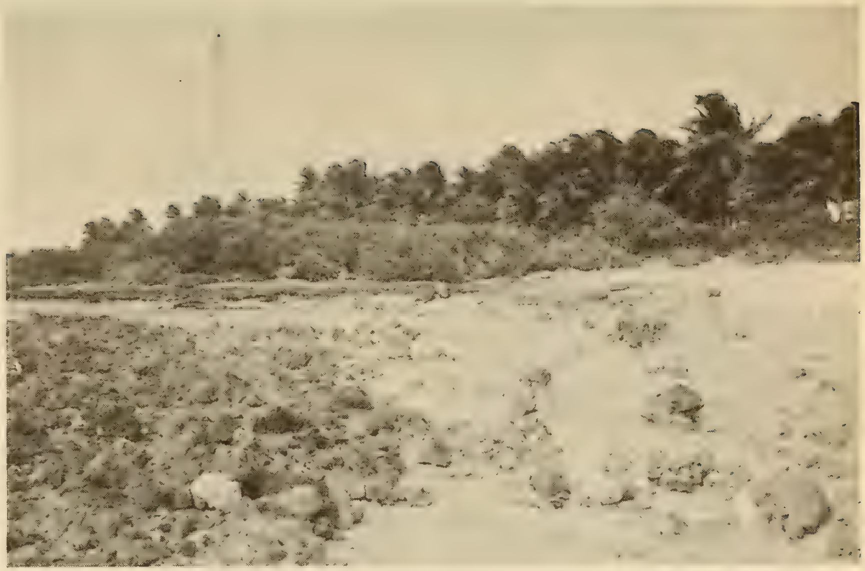
A

B

Plate 12

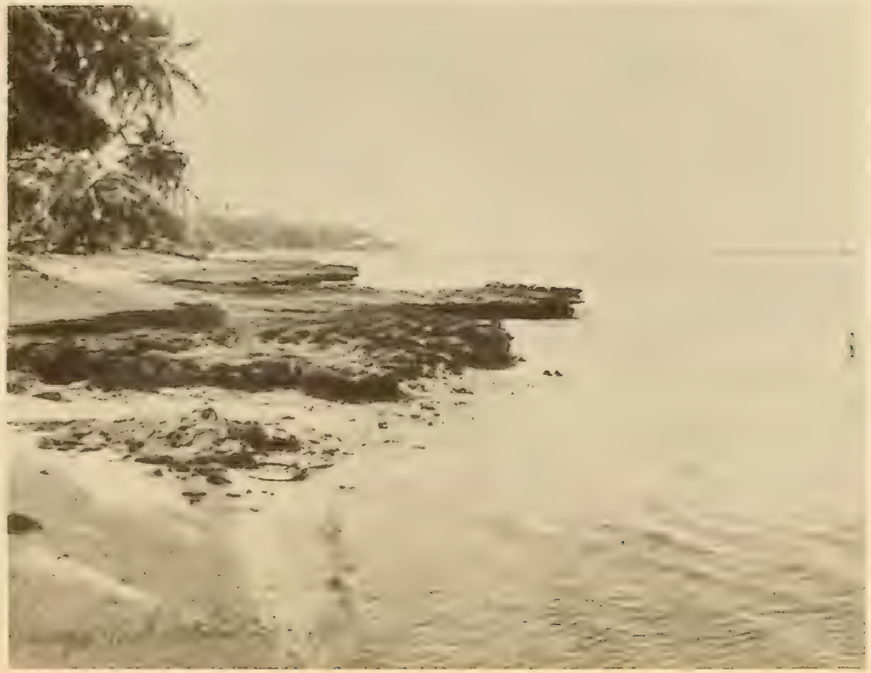


A



B

C



D

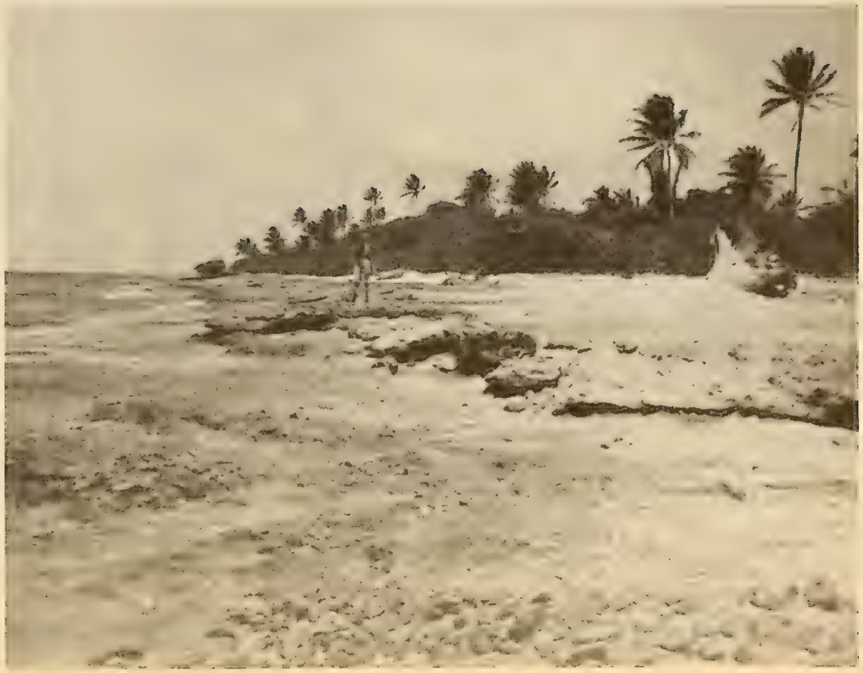


Plate 13. Boulder beach and exposed post-Pleistocene rock platform with stack and perched boulder.

A. Boulder beach with protruding exposures of post-Pleistocene rock platform, and stack with perched boulder. South side of Sibylla islet, Taongi (Pokak) Atoll.

B. Closeup of stack with perched boulder, south side of Sibylla islet, Taongi (Pokak) Atoll.

Photos by Fosberg.

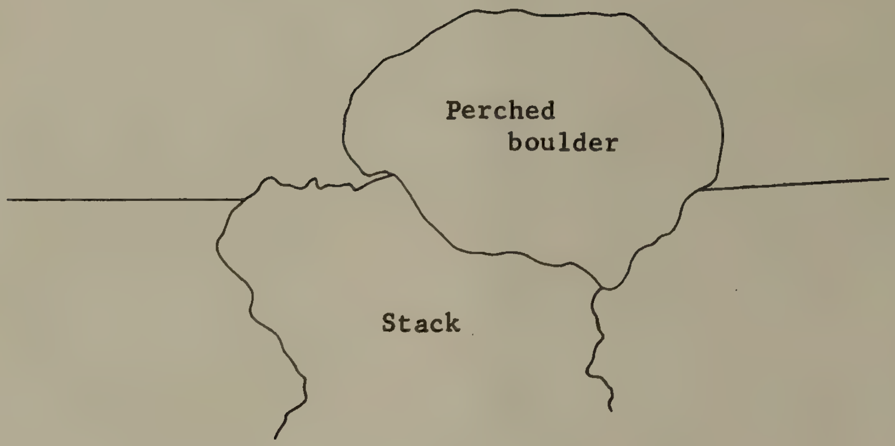


Plate 13

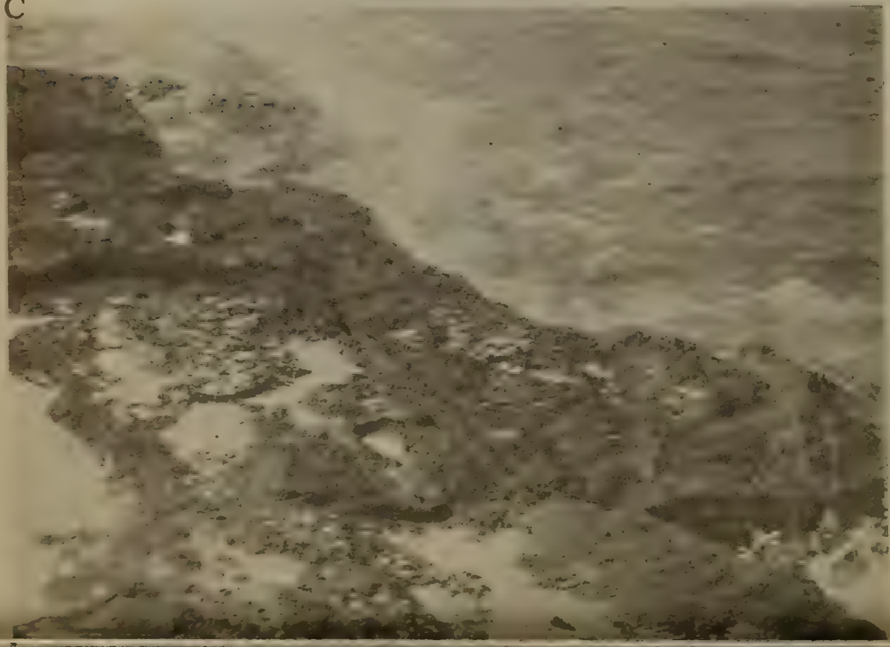
A

B

A

B

C



D

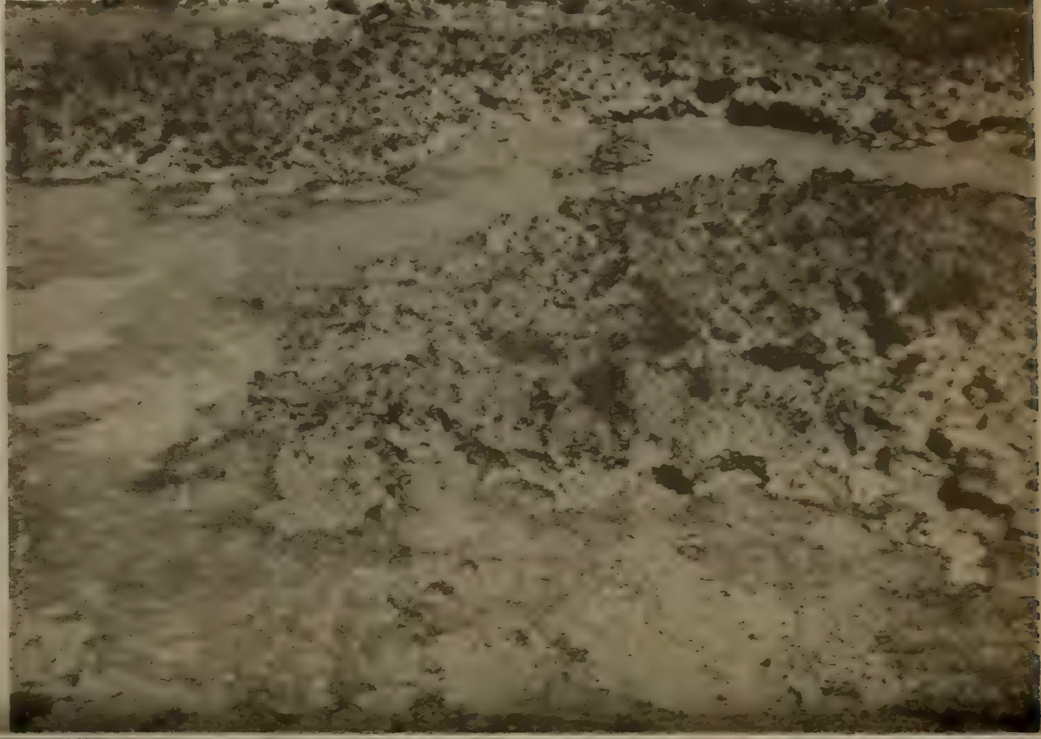
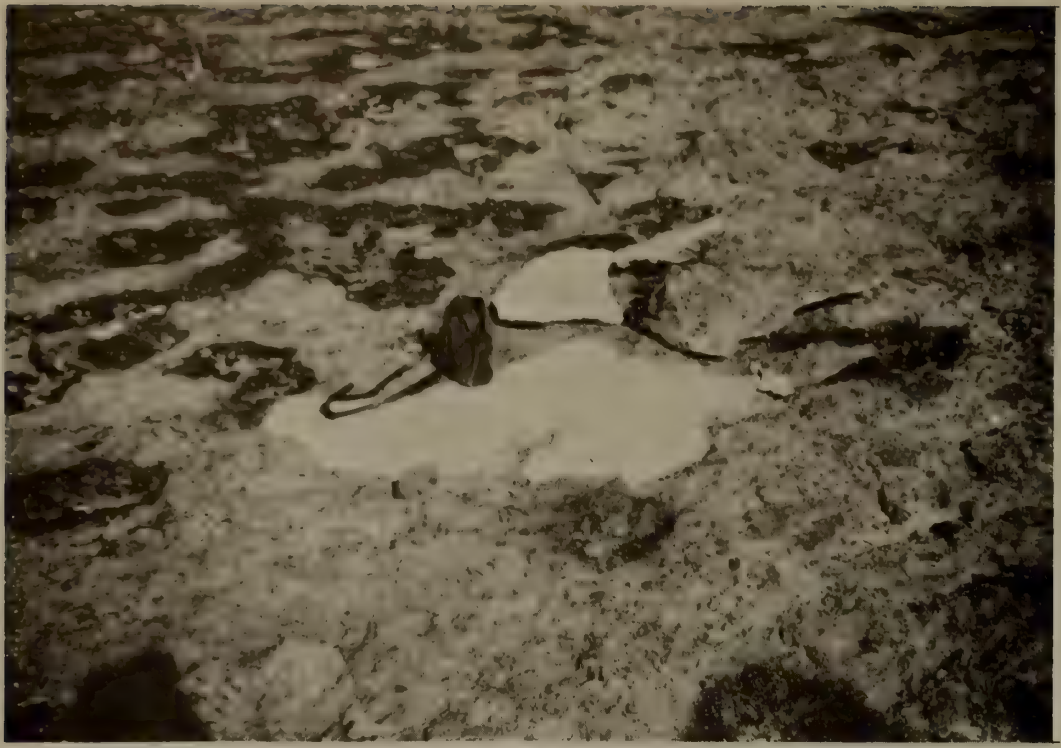


Plate 15

A

B

Plate 16



A

B

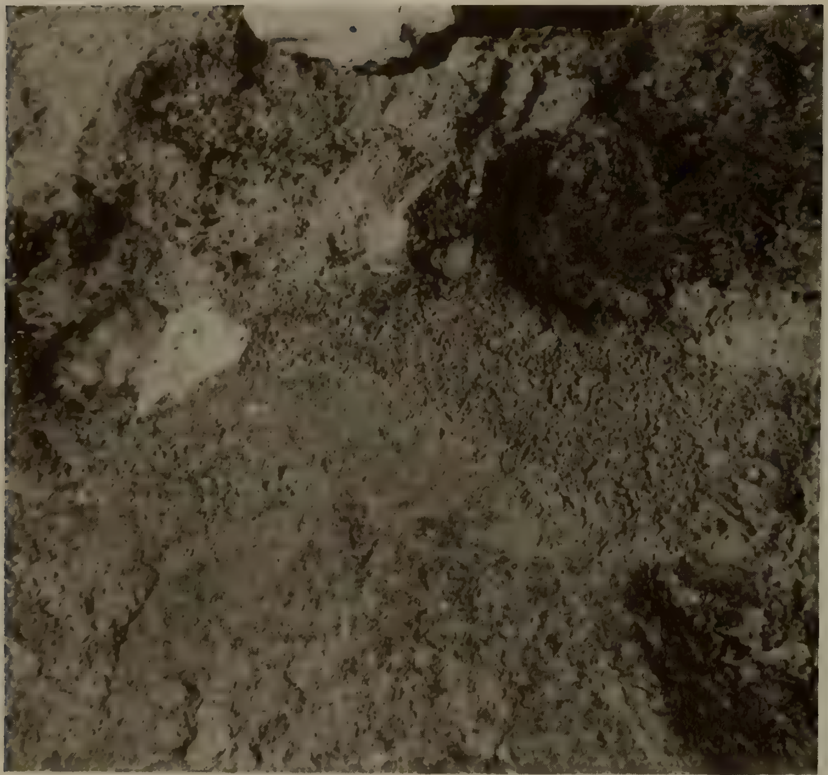
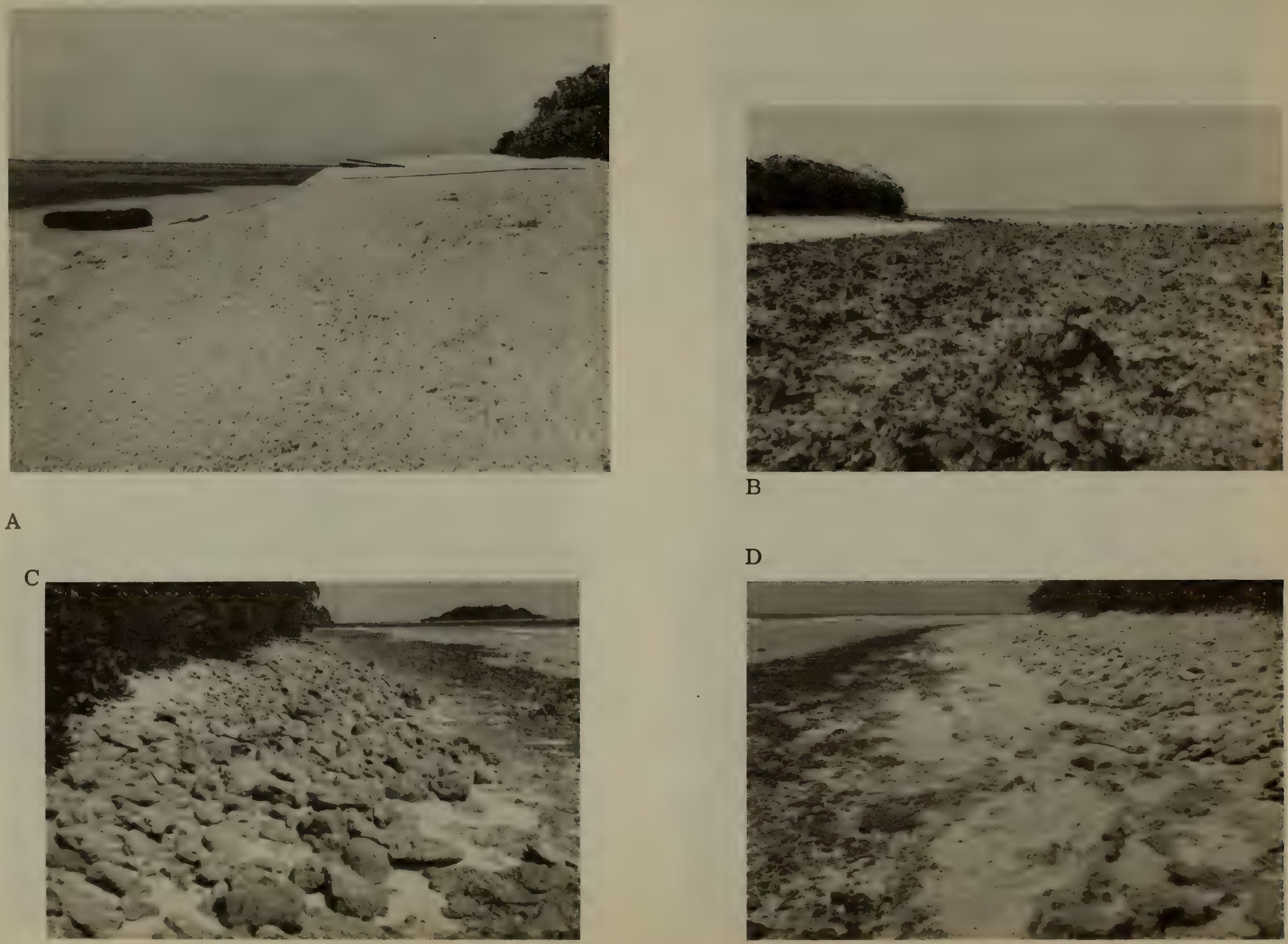


Plate 17



A

B

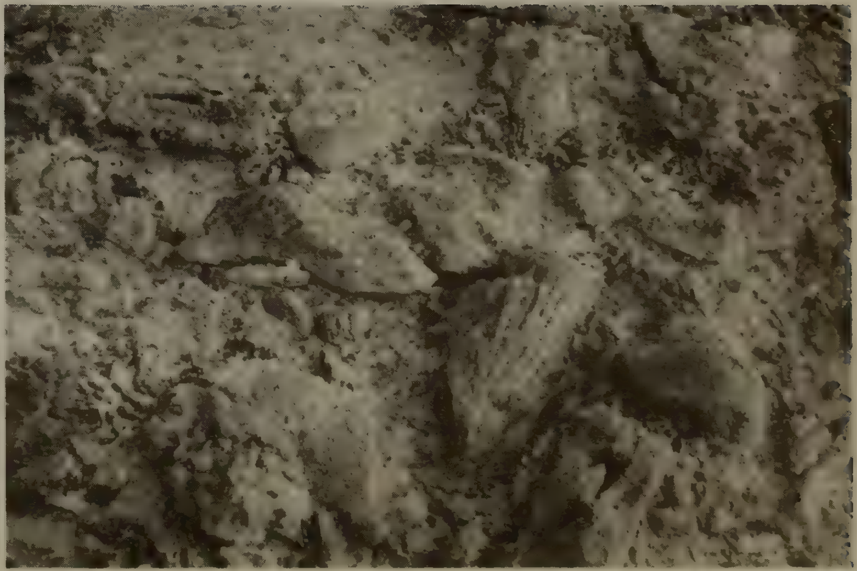
Plate 19

A

B

C

D



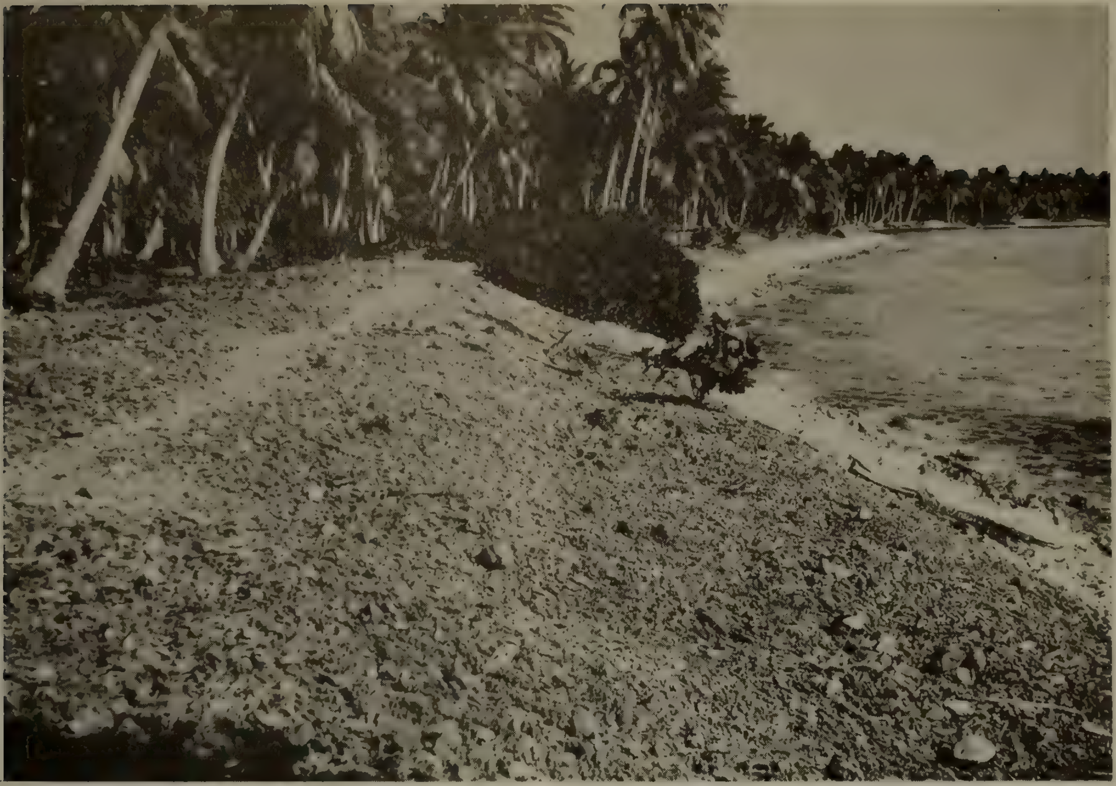
A

B

C

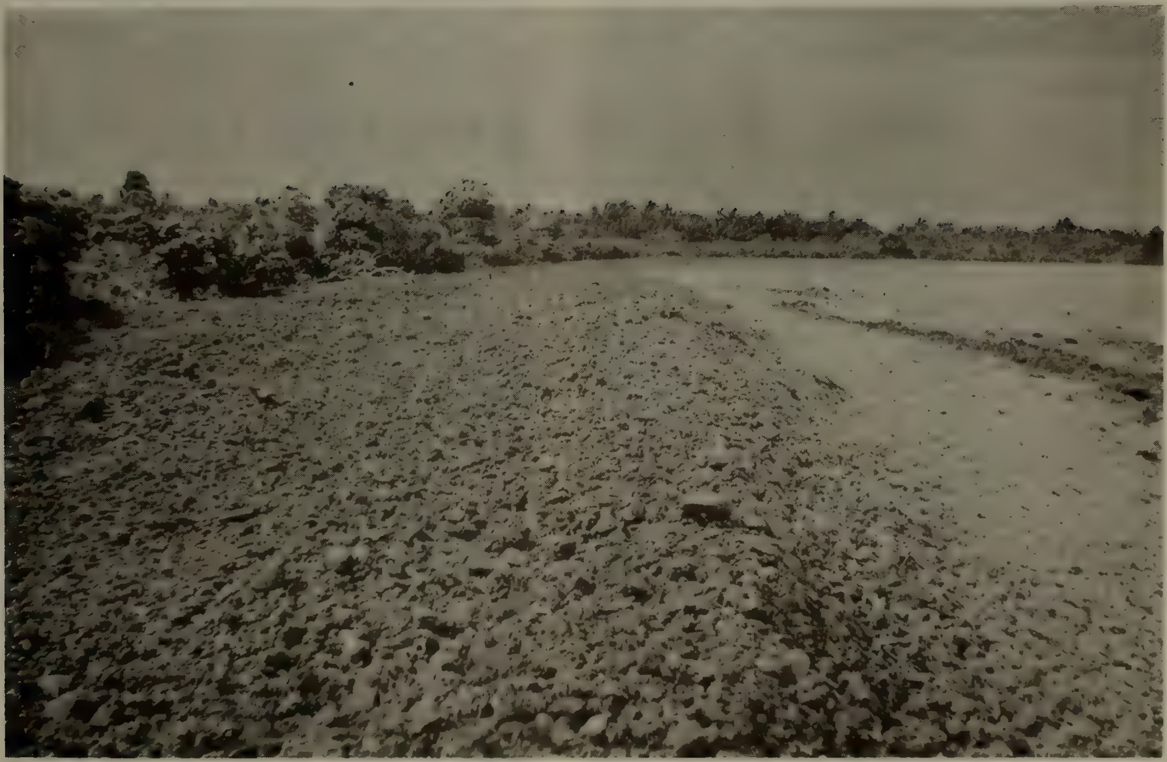
D

Plate 21



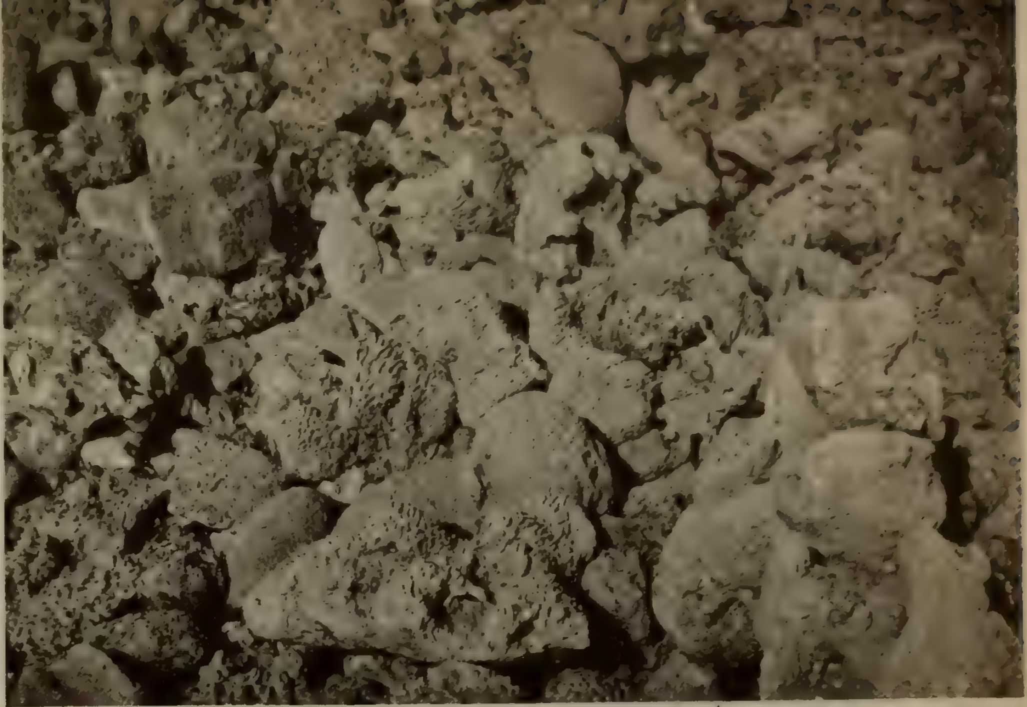
A

B



A ↑

C ↓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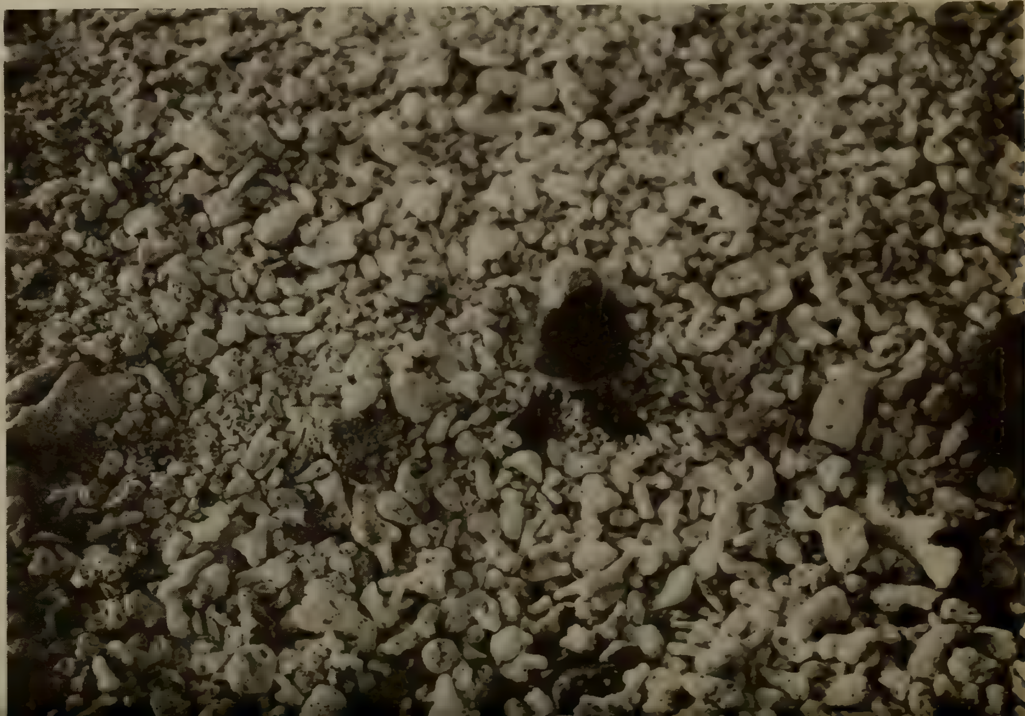
D ↓

PART II: OTHER FEATURES

by F. R. Fosberg

Soils

The loose sediments piled above high-tide level on atoll islets are composed almost entirely of clastic limestone debris, mostly of organic origin and varying in size from the finest silt-size particles to enormous boulders many tons in weight (pl. 23B). This material is remarkably uniform in chemical nature but diverse in biological origin, comprising skeletons and fragments of skeletons of such lime-secreting organisms as corals, Foraminifera, mollusks, echinoids, and calcareous red and green algae, as well as all sizes of fragments of limestone consisting of such skeletons cemented together by recrystallized calcareous and phosphatic materials (pls. 28-31, 33). These are mixed in varied proportions without a regular pattern of distribution. The texture range is extremely wide and the range in sorting is far wider than that described above for the beach materials. They are irregularly stratified (pl. 25C), the strata mostly representing stages or events in the deposition of the material. There seems to be little regularity about the vertical or areal arrangement of different grades and mixtures of these sediments, although in general the lagoon sides of the islets are more likely to be sandy in texture, and the seaward sides are more often of coarse material (pls. 21-23). The sampling, unfortunately, scarcely represents the coarser range of these sediments. Previous descriptions of similar material have been given by Sollas and others (1904), David and Sweet (1904), Cloud (1952), Newell (1954a, 1954b, 1956), Fosberg (1954), Tercinier (1955), Schlanger and Brookhart (1955), McKee (1956, 1958), and Fosberg and others (1956).

The loose, unconsolidated materials on the atolls are the parent materials of the majority of the soils developed.

The soils on the islets fall into five principal types (Stone, 1951a; Fosberg, 1954):

1. Essentially unaltered sands and gravels.
2. Stony and very stony areas.
3. Shioya series.
4. Arno Atoll series.
5. Jemo series.

These are described in detail in Part IV.

Drainage

The material of the islets is generally so porous that drainage by percolation down through the ground is perfect and almost instantaneous. There is no running surface water, except during typhoons or tsunamis, when great sea waves may sweep across the islets. Normally there is no standing surface water except where depressions or taro pits extend down to below the maximum water table. An exception to this occurs on islets subjected to intensive military traffic, such as Kwajalein. Here the surface layers become so compacted and, apparently, so cemented as to become more or less impervious. Water puddles may stand in such areas as long as 24 hours after heavy rains.

Vegetation

Most of the original vegetation of the northern Marshall Islands has been replaced by coconut plantations. This is especially true on the larger islets. Only on Taongi (Pokak) (pl. 24A, B), Bikar, and Wotho Atolls was it possible to study considerable areas of apparently undisturbed vegetation; on Lae, Ujae, Ujelang, and Kwajalein Atolls smaller areas were studied (see Fosberg, 1953, 1955; Fosberg and others, 1956). As extensive reports on the vegetation are to be published elsewhere only a brief summary need be given here.

The coconut plantations (pl. 24C, D) range in density from almost complete cover in more moist areas to quite sparse in the dry northernmost atolls. The ground cover under the trees ranges from grass and other herbs to a thick tangle of bushes, vines, and trees, depending on the climate and on how diligently the weeds are kept cleared.

On the seaward sides of most islets a belt of thick scrub and scrub forest (pl. 2A) is left to protect the coconut trees from excessive wind and salt spray. On the windward side this tends to be very dense and to slope gradually to the beach. On more sheltered sides this belt tends to be narrower, taller, less dense, and with a more abrupt slope to the beach, both because trees grow closer to the beach and because shrubs and trees are less stunted by wind and salt spray.

On smaller islets, and on areas left undisturbed on larger ones, there are several types of forest--pure stands of giant soft-wooded Pisonia trees (pl. 25), of fantastic Pandanus, of umbrella-like Ochrosia, or mixed stands of these and several hardwood species. These forests commonly have dense canopies and little undergrowth. Around the edges a dense scrub fringe gives an appearance of impenetrability.

On sand spits, bars, and narrow places on islets a sparse scrub of pioneer species (pls. 26, 27) is found, grading into forest.

On very small or very rocky islets the woody vegetation may be low and dense, or of irregularly scattered trees and shrubs with patches of sparse bunchgrass and thin low scrub; rock flats may be completely bare of vegetation. Such aspects become more and more predominant as one goes northward in the Marshall Islands, until they characterize almost the entire vegetation of arid Taongi (Pokak) Atoll (pl. 24A, B).

Principal reef-forming animals and plants

Corals, by J. W. Wells

The reef building corals of the Marshall Islands include 52 genera of the Scleractinia, 2 genera of the Alcyonaria (*Heliopora* and *Tubipora*), and 1 hydrozoan genus (*Millepora*). The skeletons of all these are aragonitic, analyses showing $CaCO_3$, 98.05-99.71 percent; $MgCO_3$, 0.09-1.11 percent; and minute amounts of SiO_2, $(Al,Fe)_2O_3$, and traces of $CaSO_4$ and $Ca_3(PO_4)_2$. The texture of the skeleton ranges from porous or spongy in such rapidly growing forms as *Acropora*, *Porites*, and *Montipora* to relatively dense and solid in such relatively slow growers as *Favia*, *Pocillopora*, and *Heliopora*.

The protean scleractinian genus *Acropora*, with a bewildering array of species (298 *named*, but less than one-third valid), is easily the dominant coral everywhere on the Indo-Pacific reefs except in regions geographically peripheral to the reef zone. Judging from its frequency in reef rock and loose debris, it accounts in many places for three-quarters or even more of the mass. Locally, according to ecological controls, *Acropora* may be quantitatively secondary to a few other genera: on algal ridges to windward, *Pocillopora* commonly is almost the only scleractinian, followed by the hydrozoan *Millepora*. Behind the ridge, *Acropora* is dominant over those parts of the reef flat that do not "dry" at ordinary low tide. On many Indo-Pacific reef flats, but only rarely in the Marshall Islands, branching *Montipora* may be locally abundant even to virtual exclusion of other corals. Near shore, especially where the substratum is of shifting loose debris, *Acropora* diminishes and dominance is assumed by species of *Porites* or the alcyonarian "blue coral" *Heliopora*. Lagoon reefs are easily dominated to considerable depths by *Acropora*, except close to the shore. On Marshall Islands reefs the overall order of quantitative importance appears to be: *Acropora*, *Porites*, *Pocillopora*, and *Heliopora*, with *Montipora*, *Astreopora*, the faviid genera (as *Favia*, *Favites*, *Platygyra*, *Goniastrea*, *Leptastrea*, *Cyphastrea*, and *Plesiastrea*), and all others much in the minority.

Foraminifera, by Ruth Todd

Four species of Foraminifera are the chief representatives of this group of animals found in the sediments and soils of the northern Marshall Islands:

Calcarina spengleri (Gmelin)
Amphistegina madagascariensis D'Orbigny
Marginopora vertebralis Blainville
Homotrema rubrum (Lamarck)

In certain of the sands the four together comprise the bulk of the material and, in some places, *Calcarina spengleri* (Gmelin) alone accounts for most of it.

The entire skeletons of these four genera are composed of calcite. All are rather thick-walled forms with numerous interior chambers and consequently they are more resistant to abrasion on the beaches than are the smaller, thinner-walled and more fragile specimens of Foraminifera that comprise the remainder of the large foraminiferal fauna of the Marshall Islands.

So far as is known at present, *Calcarina spengleri* (Gmelin) lives only on the reef flat (Cushman, Todd, and Post, 1954, p. 364). *Marginopora vertebralis* Blainville lives both on the reef flat and in water of shallow to moderate depths inside and outside the atoll. The larger, thicker and more robust forms of this species are presumed to have lived on the reef flat or in shallow water. *Homotrema rubrum* (Lamarck) is an encrustation that occurs both on the reef flat and in water of probably only shallow depth.

Amphistegina madagascariensis D'Orbigny probably does not actually live on the reef at all, although it is found there in small quantities. Elsewhere, it is very abundant. It probably lives both inside and outside the atolls from shallow to moderate depths, with larger and thicker-walled specimens (such as those in the samples listed below) originating in the shallower parts of the lagoons.

Table 1 records the distribution of these major species in three groups of samples. Samples in (a) with mainly fresh and unworn specimens, indicate little transport from their place of origin; in (b) with worn and some polished specimens, indicate long transport and (or) prolonged abrasion; and in (c), with corroded specimens, may indicate attack by acid solutions.

Algae, by M. S. Doty

In tropical seas certain algae are major accumulators of the material that becomes deposited as calcareous sediment or rock to form the atolls and islands around and on igneous rock bases (Ladd and others, 1953). These algae dominate the atoll reefs and much of the lagoon bottom area. A readily available illustrated resume of these algae has been published by Johnson (1954). Fragments of algae broken from the reef patches and atoll reef edges by wave action or the browsing activities of such animals as the parrot fishes (Scaridae) or surgeon fishes (Acanthuridae) may wash into the lagoon where they contribute to its filling or accumulate as islands on reef tops. Calcareous algae, when ingested by animals such as these fishes, are defecated largely as fine sediment.

Quantitative relationships of four major constituents of present-day reefs are given in table 2. Among the red algae three or four genera are most conspicuous on the reefs of today, *Porolithon*, *Goniolithon*, *Jania*, and *Amphiroa*.

Table 1.--Foraminifera in various types of terrestrial sediments on atolls in the northern Marshall Islands

Analyst: Ruth Todd

(a) Samples containing fresh (unworn) Foraminifera

Foraminifera	14	18	53	57	60	75	76	92	105	112	126	129	139	156	253	275
Marginopora vertebralis	X	X	X	X	X	X	X	X	...	X	X	...	X	X	X	X
Amphistegina madagascariensis	X	X	X	...	X	X	X	X	...	...	X	...	X	...	X	X
Calcarina spengleri	...	...	X	X	X	X	X	...	X	X	X	X	X	...	X	X
Homotrema rubrum	...	...	...	...	X	...	...	X	...	X	X	...	...	X	X	...

(b) Samples containing worn Foraminifera

	22	25	29	34	36	44	70	72	96	104	110	115	116	120	122	132	150	166	251	254	255
Marginopora vertebralis	X	X	X	...	...	...	...	...	X	X	X	...	...	X	...	...	...	X	...	...	...
Amphistegina madagascariensis	X	X	...	X	...	...	X	...	X	X	X	X	X	X	X	X	X	X	X	...	...
Calcarina spengleri	X	X	X	X	X	X	X	X	...	X	X	X	...	X	X	X	X	...	...	X	X
Homotrema rubrum	X	...	...	...	...	X	X	...	...	X	...	X	...	...	...	X	...	X	...	...	X
							[1] p	p			p			p					p	p	p

(c) Samples containing corroded Foraminifera

	21	23	28	71	100	102	114
Marginopora vertebralis	...	...	X	...	X	X	X
Amphistegina madagascariensis	X	X	...	...	...	X	X
Calcarina spengleri	X	X	X	X	X	X	X

[1] polished specimens.

The genus Porolithon is the builder of sea edges of reefs, it is perhaps the principal organism making up the pink stony crusts and heads that may coalesce to form the buttresses and ridges of the reef margin. These buttresses and overhangs are, on occasion, broken off by storms and deposited inland or on the reef flat, often as huge and conspicuous reef boulders. Smaller fragments make up much of the island gravels and sand grains. It is to be noted that some of the huge chunks broken from the reef edge by storms become lodged in the grooves between the marginal reef buttresses and there, after being overgrown, contribute to the roofing-over of the inward ends of the grooves. In the central Pacific the material seen in such areas, often as a pink pavement, is perhaps 90 percent Porolithon onkodes.*/

Goniolithon, another of the lime-producing genera, is a dendritically branched alga of the more inward reef flats and passes between atoll islands. It does not form large detrital pieces, being friable, and is most notably a sand producer. Jania and Amphiroa are flexible jointed coralline algae that form patches of branches a few centimeters high and a millimeter or so in diameter. Upon breaking loose from their site of growth on the reef flats they die, and the soft parts of the joints decay leaving calcareous sediment or sand. This red algal detrital material around Johnston Island (Emery 1956, p. 1511) may be the principal lagoon-filling sediment. In many places a green alga, Halimeda, is the principal constituent of the sand that builds the islands, as in the Caribbean and Bermuda, or one of the principal constituents of lagoon sediments, as in the northern Marshall Islands atolls (Emery and others 1954, p. 58). Halimeda is composed of branches that are made up of heavily calcified, flat, waferlike segments. These segments persist as sand grains of a rather coarse kind after the death of the plant. While Halimeda does grow on reef flats, especially the broader and what we feel to be the older reef flats, it grows most conspicuously in the lagoons where it may densely cover the sides of the lagoon reefs and reef patches and form meadows on the shallower bottoms.

The chemical composition of these algae is shown on table 3. Further studies of chemical composition are reported by Clarke and Wheeler (1917), Lemoine (1911, p. 38-43), and Johnson (1954). The high magnesium content of the red algae is to be noted. This may be one of the sources of the dolomitizing magnesium salts in atoll areas. Whereas there are theories that certain phosphorites have arisen under marine conditions upon decay of marine organisms, from the very white color of young fossil material and the low P_2O_5 content, it is unlikely that these marine algae play such a role. Little is yet known of the biomass of these rocklike organisms. From the chemical analyses it is clear that they are mostly inorganic and thus could be regarded as mostly nonliving.

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*/ The oft-referred-to genus Lithothamnion is, virtually, not to be found on reef surfaces.

Table 2. - Quantitative relationships of the four major constituents of reefs

Constituents	Pearl and Hermes Reef [1]	Southeastern Florida [2]	Bahamas [2]	Murray Islands Australia [1]
Algae, calcareous	48.5	25.1	18.0	42.5
Mollusk	17.8	17.5	12.2	15.2
Coral, madreporarian	16.6	9.3	8.2	34.6
Foraminifera	6.3	9.0	17.3	4.1
Total (percent)	89.2	60.9	55.7	96.4
Constituent ratios				
Algae/coral	2.92	2.70	2.20	1.23
Algae/mollusk	2.72	1.43	1.47	2.79
Algae/Foraminifera	7.70	2.80	1.04	10.03
Mollusk/Foraminifera	2.82	1.94	.71	3.71
Mollusk/coral	1.07	1.88	1.49	.44
Coral/Foraminifera	2.64	1.01	.47	8.44

[1] Data from T. W. Vaughan, 1917.
[2] Data from Thorp, 1936, p. 52.

The results of Odum and Odum (1955) indicated that there is uniform concentration of chlorophyll (equivalent to between 0.05 and 0.10 gm/cm of Codium edule, dry weight) over the reef surface regardless of substratum, whether it be coralline crust, animal coral, or detrital. Sargent and Austin (1949) and Odum and Odum (1955) have shown that there may grow and be deposited as much as 1.4 to 1.6 cm of material per year over a reef surface. Under more ideal conditions growth may be much faster. For all practical purposes, reef surfaces are generally in equilibrium with as much material being removed by erosion as is deposited by the living organisms. Thus this increase of about 1.5 cm per year times the area involved can be used as a figure for calculating a maximum amount of material depositable as clastics that could become soil.

Table 3.--Partial chemical composition of some sediment-forming red algae as percent of dry weight

Sources: Clarke and Wheeler, 1917; Lemoine, 1911; Johnson, 1954

Algal species	CO_2 in ashed samples[1]	CO_2 in samples not ignited[1]	Organic matter	Moisture in air-dried samples	SiO_2	R_2O_3	CaO	MgO	SO_3	P_2O_5	SrO	Total
Porolithon	...	37.5	[2]12.9	1.34	Tr	Tr	33.3	7.49	.68	1	1.03	94.2
onkodes	...	35.3	[2]12.9	1.40	do.	do.	32.7	7.16	2.32	1	1.21	93.0
Porolithon	3.43	36.8	12.7	.67	do.	do.	34.0	7.64	1.03	.25	1.10	94.2
gardneri	2.96	37.4	11.8	.68	do.	do.	34.3	7.62	.28	.38	1.18	93.6
Porolithon	3.27	28.2	21.5	1.72	do.	do.	31.9	8.62	2.05	1	.97	96.0
aequinoctiale	2.88	28.4	21.0	1.54	do.	do.	31.9	8.46	1.84	1	1.10	94.2

[1] Determined by HCl titration. [2] Loss in weight to 550° C.

Note: These percentages should not total 100 percent, as all the constituents were not determined. The figures for CO_2 in ashed samples should not be included in totals.

Legends of plates

Plate 23. Miscellaneous deposits.

- A. Dunes on sand spit, south end of Enajelar islet, east side of Ailuk Atoll.
- B. Large boulder in interior of Kamwome islet, Taongi (Pokak) Atoll, apparently carried some hundred meters inland by storm waves.
- C. Mass of pumice pebbles on surface of ground, interior of south extension of Ebbetyu (Ebeju) islet, Ujae Atoll.
- D. Top of broad boulder ridge, apparently piled up by typhoon, Utirik islet, Utirik Atoll.

Photos by Fosberg.

Plate 24. Types of vegetation on islets.

- A. *Lepturus* grassland with shrubs of *Sida fallax* and scattered trees of *Messerschmidia argentea*, boulder covered with guano, on Shioya soil series, Kamwome islet, Taongi (Pokak) Atoll.
- B. Sparse, half-dead *Messerschmidia* woodland on cobble flats, Kamwome islet, Taongi (Pokak) Atoll.
- C. Coconut grove with thick undergrowth on cleared, disturbed Jemo soil, Jemo island.
- D. Grassy opening in coconut grove on Shioya soil, Jemo island.

Photos by Fosberg.

Plate 25. *Pisonia* forest and forest soil.

- A. Giant *Pisonia grandis* tree, Ebbetyu (Ebeju) islet, Ujae Atoll.
- B. *Pisonia* forest with grassy ground cover, Jemo island.
- C. Soil test pit in *Pisonia* forest on Bikar islet, Bikar Atoll, showing buried hardpan layer of Jemo soil series.
- D. *Pisonia* forest, Bikar islet, Bikar Atoll, showing dark humus layer on the surface of the ground, Jemo soil series.

Photos by Fosberg.

Plate 26. Shore and sand-flat vegetation.

- A. Mixed forest on stony soil, Bokerok islet, Ujae Atoll. Wave-cast log, probably Douglas fir from northwest America, in foreground.
- B. Scrub forest of *Pemphis acidula* on rock platform surface, Jabwe islet, Ailuk Atoll.
- C. Well-developed fringe of *Scaevola* scrub at top of gravel beach, leeward side, Kalo islet, Ujelang Atoll.
- D. Darkening of bare coral sand by crust of blue-green algae, open areas on west end of Lae islet, Lae Atoll. This crust may contribute to the nitrogen supply of the soil.

Photos by Fosberg.

Plate 27. Pioneer vegetation.

A. Low shrubs of Pemphis acidula on denuded rock platform surface, Jabanngit islet, Ailuk Atoll.

B. Young Scaevola and Messerschmidia plants colonizing gravel bar on south reef of Lae Atoll.

C. Scaevola and Messerschmidia colonizing gravel flat on Kabben islet, Wotho Atoll.

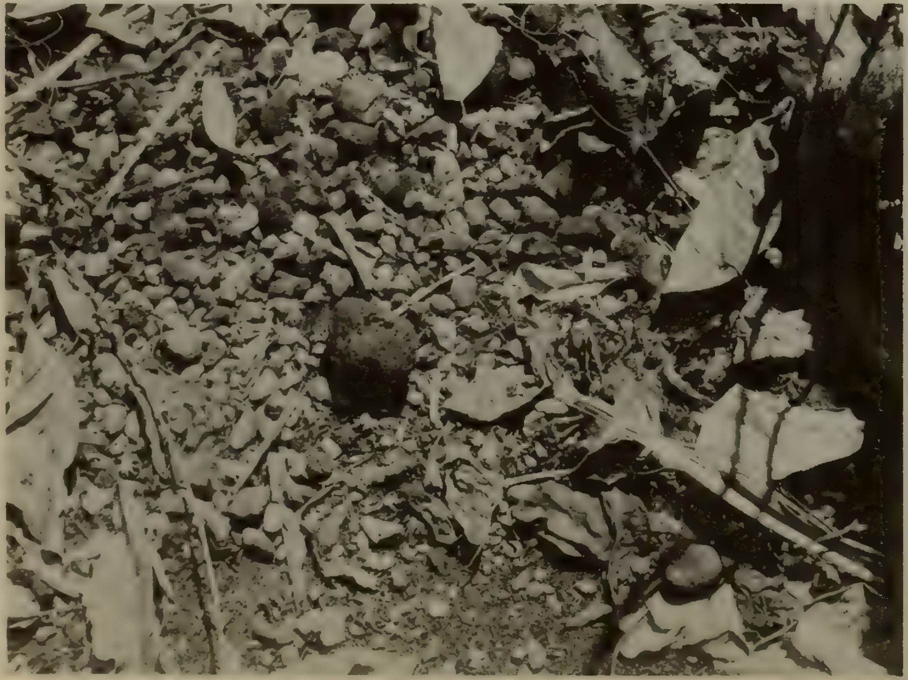
D. Young Scaevola plants colonizing upper part of gravel beach, lagoon side of Bwdije (Breje) islet, Taongi(Pokak) Atoll.

Photos by Fosberg.

Plate 23

A

B

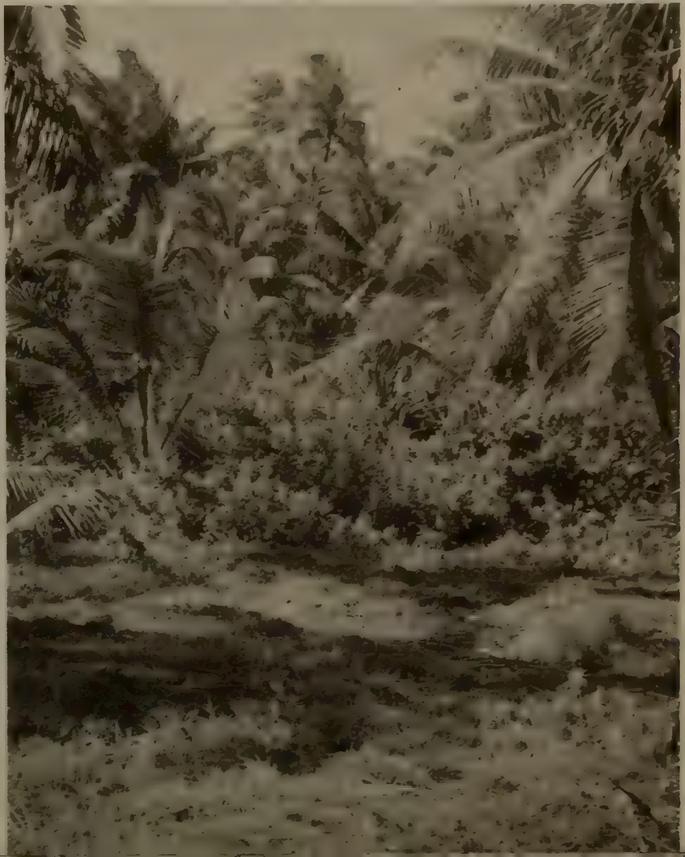

C

D

A

B

C



D

Plate 25

A

B

C

D

Plate 26

A

B

C

D

Plate 27

A

B

C

D

PART III: LABORATORY EXAMINATION OF UNCONSOLIDATED SEDIMENTS

by Dorothy Carroll

Unconsolidated calcareous material occurs on the beaches surrounding the islets on the atolls, and in the interiors of the islets as soils. Beach sands have been described from Bikini by Emery, Tracey, and Ladd (1954), Onotoa by Cloud (1952), Raroia by Byrne (in Newell, 1954b, 1956), Kapingamarangi by McKee (1958, 1959), and from various other Pacific Islands by Wentworth and Ladd (1931). The soils on Arno Atoll have been described by Stone (1951a,b), and on Bikini by Stone (in Emery and others, 1954). Fosberg (1954) gave a general description of the soils of the northern Marshall Islands and recognized a new soil type, the Jemo soil.

The materials present as beach sands together with larger fragments, solid reef materials, and organic matter, provide the parent material for the soils. The sands described here are representative of the finer rather than the coarser materials of the beaches.

The atolls from which beach sands were collected and described, and the number of samples from each atoll are: Ailuk 1, Bikar 15, Kwajalein 8, Lae 2, Likiep 2, Taka 4, Taongi (Pokak) 31, Ujae 2, Ujelang 8, Utirik 5, and Wotho 7, a total of 85 samples. The localities are listed in Appendix I and indicated on figures 5-15. A description of 28 of these samples is given in Appendix I.

The atolls from which soils were collected and described, and the number of samples from each atoll are: Ailuk 11, Bikar 26, Jemo 18, Kwajelein 5, Lae 12, Likiep 6, Taka 29, Taongi (Pokak) 15, Ujae 16, Ujelang 3, Utirik 22, and Wotho 23, a total of 186. When the samples were collected, a number of pits was dug through the soils so that material from different depths could be collected. Each vertical sequence of samples is referred to as a soil profile. The positions on the islets from which soil profiles were collected (except the Kwajalein profiles) are shown on figures 16, 17, and 18. Field descriptions of the analyzed soils are given in Appendix II. Unanalyzed soils are indicated by appropriate symbols on the maps in order to give a more adequate idea of the distribution of the several soils series within the islets.

Size distribution

To obtain the size distribution of the materials in the sands and soils, all the samples were sieved dry through a set of U.S. Standard Sieves to give grades as originally described by Wentworth (1922). The sizes and sieves are:

Size, mm	Descriptive term	Sieve No.*
above 16	Pebble	
16 - 8	Pebble	
8 - 4	Pebble	
4 - 2	Granule	5
2 - 1	Very coarse sand	9
1 - 0.5	Coarse sand	18
0.5 - 0.25	Medium sand	35
0.25 - 0.12	Fine sand	60
0.12 - 0.06	Very fine sand	120
less than 0.06	Silt	230

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*Sieve through which sample passed; it was retained on the next finer sieve in the series.

In some samples the coarser material, generally coral fragments, was removed with a one-half inch (12.7 mm) or a one-quarter inch (6.35 mm) sieve before the finer grades were sieved.

The samples collected by F. Stearns MacNeil were sieved by him through sieves 3, 4, 9, 14 and 35, corresponding to openings of 6.35, 4.76, 2.0, 1.9, and 0.42 mm, respectively. These sieves do not correspond to those used for most of the samples, but are sufficiently close not to cause significant differences in the size distribution of the sands. MacNeil's material passing the 35 mesh sieve was not originally sieved into finer fractions, but as a number of these samples contained more than 50 percent by weight of smaller than 35 mesh grains, these were resieved to conform to the remainder of the samples.

Biotic composition

The beach sands and soils consist of reef organisms and those that lived in the lagoons. The original shape, size, and buoyancy of these organisms determine to some extent the size distribution, sorting, and general appearance of these materials. The admixture of organic matter with calcareous sands forms the soils of the atolls.

All the reef organisms, as described by Wells, Todd, and Doty (on pages 25-30) have characteristic sizes, shapes, and habits. Corals and algae of the reefs are massive. Large fragments are broken off by waves and carried to the shores of the islets. Halimeda in the lagoons breaks into fragments about one-half to one cm in length. The commonly occurring Foraminifera, Calcarina, Marginopora, and Amphistegina, range from about one-half to 2 mm in size, although some are smaller and a few larger. The detached spines of Calcarina spp. are generally unbroken in the finest fractions of the sand. Sea urchin spines are broken into all sizes from large to small fragments.

Each grade size of each sample of beach sand and of soil was examined under a binocular microscope to identify the kinds of organisms present. Estimates were made of the percentages of major constituents in each sample. The results were plotted as histograms combining the grain size and biotic composition.

The composition of the various grade sizes was found to be:

Size, mm	Faunal composition
Larger than 16, and 16 - 8	Large whole or broken corals; large fragments of algae; large shells
8 - 4	Coral, algae fragments, shells
4 - 2	Coral, algae fragments, shells
2 - 1	Foraminifera, broken coral, algae
1 - 0.5	Foraminifera, broken coral, algae
0.5 - .25	Few small Foraminifera, mostly broken pieces
0.25 - .12	Broken, unidentifiable fragments
0.12 - .06	Broken, unidentifiable fragments
Smaller than 0.06	Broken, unidentifiable fragments

The appearance of these materials is shown in Plates 28-30.

Mineralogic composition

by John C. Hathaway

The various size fractions of 19 samples from 6 soil profiles were examined by X-ray powder diffraction methods to determine their mineralogic composition, and to reveal any variations occurring amongst the different size grades as well as within the soil profiles.

A sample of each fraction was ground to pass a 230-mesh (0.06 mm) sieve and was packed into an aluminum sample holder. Care was taken to minimize the preferred orientation of the particles. An X-ray diffractogram was then made of each sample, and the amount of calcite and aragonite present determined by comparison of the intensity of the most strongly diffracted lines of the minerals. The interplanar spacing represented by the strongest calcite line, $\underline{d}$ (104), was also measured for each sample. The results of the X-ray examinations are shown in figure 19, where the approximate amounts of calcite and aragonite in each size fraction are shown on histograms of the particle size distribution for the individual samples. There was found to be a variation in $\underline{d}$ spacing of the strongest reflection of calcite (104) in the material of the size fractions. Inasmuch as the organic materials varied in chemical composition, some samples gave two strong $\underline{d}$ (104) reflections for calcite.

The significance of the variation of the interplanar spacings in calcite is discussed by Chave (1952, 1954a, 1954b) and by Goldsmith, Graf, and Joensuu (1955). They have shown that decreases in the $\underline{d}$ (104) spacing from those of pure calcite are the result of the smaller unit cell that occurs when magnesium substitutes for calcium in the calcite structure, and that the amount of magnesium can be correlated with the amount of shift in spacing position. Goldsmith, Graf, and Joensuu (1955) show this shift to amount to about 0.0029 Å per mol percent $MgCO_3$. Magnesium substitution has not been observed in aragonite.

In these Marshall Islands samples d (104) was measured to the nearest 0.01 Å, which represents increments of about 3.5 mol percent $MgCO_3$. The total variation in spacing found was 0.06 Å (2.98 to 3.04 Å), representing about 20 mol percent $MgCO_3$. Magnesium substitution increases upwards in the graphs (fig. 19). Conversion of mol percent to weight percent is made by using the following formula:

$$\text{Weight \% } MgCO_3 = \frac{84.33 \text{ X mol \% } MgCO_3}{84.33 \text{ X mol \% } MgCO_3 + 100.09 \text{ (100-mol \% } MgCO_3)}$$

Figure 20 shows the average particle size distribution for all the samples with the average amount of calcite and aragonite in each size grade. The number of samples in which a given type of material was dominant was determined for each grade size, and the percentage figure for the occurrence of the type is shown over each histogram block. At the top of the graph the average calcite d (104) spacing is given.

Figure 21 shows the aragonite content of the different grades as a percentage of the total amount of material in each size fraction.

A correlation between aragonite content and type of material is distinctly present in figure 19. Aragonite content is high in the coarse fraction where coral is the dominant constituent, and decreases considerably where algae and Foraminifera make up a large proportion of the smaller grade sizes. The rise in aragonite content in the 0.5-0.06 mm range reflects the presence of coral fragments mixed with fragments of Foraminifera and algae. The relative dearth of aragonite in the 2-0.5 mm grades as shown in figure 19 also suggests that the coral fragments are either less common or relatively unstable in this size. The low content of aragonite is possibly due to the relative instability of the mineral in fine particles. The wide range of composition shown by the extremes in the coarser fractions in figure 21 arises from the difficulty of sampling the large coral fragments representatively.

The calcite in these samples is high in magnesium as shown by the relatively low d (104) spacings. Calcite of more than one composition is present in 8 of the samples as revealed by double maxima in the region of the d (104) spacing. A distinct decrease in the amount of magnesium occurs in the less than 0.06 mm fraction of 16 of the samples. This is reflected in the upper curve of figure 20 showing the average d (104) spacings of the samples. A similar, although smaller, decrease occurs in the coarsest fraction. The calcite present may be the fine-grained material low in magnesium that occupies the many small cavities in the coarse coralline material. Algae in the coarse fractions tend to show high magnesium contents for most of the samples. Only in sample 62 (fig. 19) does a low-magnesium calcite occur where algae are important constituents, and there only as minor members of two types of calcite. An alternative possibility for the occurrence of low-magnesium calcite in the coarser fractions is the alteration of aragonitic materials to calcite. In this situation low-magnesium calcite should not be confined to the coarsest and finest fractions but should be found in the medium grades also, inasmuch as aragonite in the smaller fragments of coral might be expected to alter as readily as it does in the coarser fragments. However, "contamination" of fragments by fine-grained, magnesium-free calcite may be minor in the medium grades because the greater amount of working and washing that produced the fragments of these grades might tend to free the altered material. The liberated low-magnesium calcite would then appear in the finest fraction. If such alteration takes place it probably does so before deposition of the material in its present environment. Alteration in a soil profile would be expected to remove aragonite at the point of greatest weathering, presumably near the surface. In figure 22, all the profiles except 30 show increases of aragonite toward the surface, suggesting that alteration of aragonite to calcite is not important in the soil-forming processes in the soils studied. This, together with the erratic variations of mechanical composition at different depths in the profiles, suggests that depositional factors are more important in determining the calcite:aragonite ratio in these soils than is alteration of the materials in place. The depositional factor should be assessed in the light of the low rainfall that prevails in many of the areas from which soil samples were collected.

Analytical treatment of grain size distribution data

The data for grain-size distribution and biotic composition of all the beach sands were plotted as histograms, and the histogram for each sample is placed on the outline map of the atoll from which it was collected in figures 5-15. These histograms show the similarities and dissimilarities between samples collected from different positions on the same atoll and from the same geographic aspects on different atolls. Cumulative frequency curves were drawn for the data so that the median grain diameter, the sorting coefficient, and skewness could be calculated. Trask's (1932) sorting coefficient, $So=\sqrt{Q_3/Q_1}$, where Q_3 is the coarse quartile and Q_1 is the fine quartile of the distribution, and skewness, Q_3Q_1/Md^2 were used. The mean diameter for each sample of sand was calculated by a modification of a formula suggested by Folk and Ward (1957, p. 12), $M = \frac{\phi\,16 + \phi\,50 + \phi\,84}{3}$. The modification consisted of using the grain diameter instead of the phi notation.

The skewness or asymmetry of the distribution curve of the grain-size distribution is also used to describe the samples. Skewness in sedimentary materials is not well understood, but it has been suggested by Krumbein and Tisdel (1940) that grain distributions with excess coarse grains (positive skewness) indicate disintegrating igneous rocks, whereas grain distributions with excess fine grains (negative skewness) indicate disintegrating sedimentary rocks. However, the size distribution in the Northern Marshall Islands beach sands is dependent on both the kinds of organisms present and on the sorting by waves and wind to which they have been subjected. The skewness figures for these sands are given to show the kind of distribution that occurs. The skewness is caused primarily by the presence of certain organisms; for example, a sand consisting almost entirely of one species of Foraminifera has perfect sorting and skewness. Skewness is, therefore, a measure of the organisms present as well as an indication of their slightly broken nature. The sands appear to have had their finest material washed out.

Size distribution of beach sands

The results of the mechanical analyses of the beach sand samples together with the median grain size, sorting coefficient, and skewness are given in Table 4.

The size distribution of the beach sands collected on the seaward and on the lagoon beaches of the various islets is similar to that found by Emery and others (1954, p. 38) on Bikini Atoll. The beaches are similar from islet to islet even though the individual samples collected on any beach may vary. In the size distribution of beach sands the frequency of the modes (or maximum grades) as shown in figure 23 is as follows:

Grain size, mm	Percent of total
2 - 1	21
1 - 0.5	48
0.5 - 0.25	17

In no sample of these beach sands is there a primary mode in the fractions finer than 60 mesh (0.25 mm). Secondary modes, indicating an admixture of different materials have a wider spread and include a few maxima in the 0.25-0.125 mm and the 0.125-0.06 mm grades. It has been observed that well-worn material does not seem to become much finer than 60 mesh (0.25 mm), indicating a lower limit for abrasive action to take place. Finer material has probably been winnowed out by waves and currents.

Size distribution of material in soils

The results of the mechanical analyses of the soil samples together with the median grain diameter, sorting coefficient, organic carbon, and pH of the soils, are given in table 5.

Physically the atoll soils resemble the beach materials. Mechanical analyses show that comparisons between the two can readily be made on this basis. It has been noted by Stone (1951a, p. 14) that many soil profiles are composite and consist of alternate layers of calcareous material and organic matter. The calcareous materials in which soils are developed are somewhat more heterogenous in size than the beach materials that were selectively collected as sands. The loose sediments piled above high-tide level on atoll islets range in size from the finest silt-size particles to enormous boulders of many tons in weight. Such material is similar to that in the beach sands but it also contains massive limestone composed of cemented skeletons of calcareous organisms. The soil materials are mixed in varying proportions with no very regular pattern in their distribution. The texture range is extremely wide, and the range in sorting is far wider than that described for the beach materials. The materials are irregularly stratified, the strata mostly representing stages or events in deposition. There seems to be little regularity about the vertical or areal arrangement of the different sizes and mixtures of these sediments, although in general the lagoon sides of the islets are more likely to be sandy in texture, whereas the soils from the seaward sides are more often of coarser material. The samples of soils collected represent the finer rather than the coarser parent materials.

One hundred and ten mechanical analyses were made of soil materials. Forty percent of the soils have the mode (or maximum grade) in the 1.0-0.5 mm grade, and 34 percent in the plus 8 mm grade; that is, such soils consist of large fragments of coral that have not been broken up either by abrasion or by solution. It is noteworthy that there is very little fine material, where present it consists of a mixture of fine organic matter and fine calcareous grains similar to those in the beach sands. Other soils consist of organic matter plus very coarse gravel; in some of these soils the organic matter is the most important constituent.

The size distribution of the soil material is given in table 5, where the grade sizes are the same as those used for the beach sands, so direct comparisons between the soils and beach sands can be made. In figures 24 to 28 the data are plotted as histograms, the samples being arranged in vertical sequence as they occurred in the field.

Sorting

The coefficient of sorting (So) (Trask, 1932) ranges from 1.0 to 2.76, with the majority of the samples, whether from seaward beaches or lagoon beaches, falling around 1.50. The sands are therefore considered well sorted by Trask's original definition. However, many naturally occurring disintegration products that have not been transported or winnowed by waves and wind have a sorting coefficient not much greater.

Sorting in these beach sands is due to two principal factors: (1), presence of calcareous organisms; and (2), movement of material on the beaches by waves, currents, wind, or any combination of these agents. The first factor brings in the size distribution in the sands, and it does not seem possible, until additional observations have been made on beach processes, to isolate either of these two factors. The histograms in figures 5 to 15, in which the major organic constituents are shown, indicate how the size distribution is in part dependent on the material that has been furnished by reef and lagoon organisms to the sands. Similarly, sands having the best sorting may consist entirely of one organism, as in the foraminiferal sands, or of completely comminuted fragments that have actually been sorted by waves and wind. Table 6 was prepared to assess the significance of the coefficients of sorting found in the sands.

In table 6 the constituents are listed as major constituents if any one makes up 50 percent or more of the sand. The "mixed assemblage" category indicates that the sand has two or more constituents neither of which is dominant. The column headed "none dominant" indicates that the sand consists of varying proportions of all the constituents. The columns headed "sorting caused by" are used to assess the principal factor in the sorting coefficient obtained from the sieve analyses.

Various categories may be recognized, as follows: If one kind of organism is dominant in a sand (Category A) then the sorting is considered to be due to the presence of that organism, although its presence may be due to selective transportation from its place of origin and to removal of other constituents originally present by winnowing; Category B contains sands in which there are two or more constituents of considerable importance, neither of which is dominant in weight percent of the sand; Category C (A plus B) contains sands in which a number of constituents may or may not be recognizable because of abrasion by reworking on a beach. In table 6 there are 21 sands in Category A, 16 in Category B, and 35 in Category C. The average sorting coefficient is:

Category A, 1.46 (range 1.10-2.60, median, 1.33)
Category B, 1.62 (range 1.10-2.02, median, 1.70)
Category C, 1.65 (range 1.00-2.65, median, 1.64)

The median figures for the sorting coefficient, 1.33, 1.70, and 1.64, respectively for the different categories indicate that the sands containing the highest percentage of one kind of organism have, on the whole, a more perfect sorting than those containing a variety of organisms, or those that are made up of comminuted fragments. However, the fact that some sands do contain only one kind of organism is a result of proximity to source of supply and of transportation conditions.

Skewness of the size distribution

In general the sands are skewed positively, that is, the asymmetry of the distribution curve (Sk) is caused by the admixture of coarse material. Seventeen (23 percent) of the sands have symmetrical distribution curves (Sk, 0), and there is only one sand that has a negative skewness (T30, table 6). One third of the sands that contain recognizable organisms as a major constituent have symmetrical distribution curves, whereas less than a quarter of the "mixed" sands (Category C) have symmetrical curves. As these sands all contain recognizable calcareous organisms, the skewness is considered to be caused primarily by them.

The skewness of the frequency curve for sands is reduced by the presence of one particular kind of organism; for example, Foraminifera that have a small range in size. Calcarina spengleri has a diameter of between 1 and 2 mm, so a sand composed entirely of this Foraminifer will have Sk, 0 and So, 1.0. The presence of a concentration of any one type of organism that can take the place of individual mineral grains in making up a sand will have a similar effect.

Sufficient details concerning the localities where the samples were collected are not available, but a few suggestions can be made. Positive skewness occurs in more than three-quarters of the sands examined, irrespective of their situation on the seaward or lagoon side of the islands. Sample T30, from the southern seaward beach of Bwokwla islet, Taongi (Pokak) Atoll, is the only one that has negative skewness, indicating an admixture of fine material. T30 is a well sorted sand with So, 1.45; it has 80 percent of the grains between 1.0 and 0.5 mm in diameter, and these grains consist of comminuted fragments. The fact that most of the beaches examined do not contain extremely fine sand shows that such material, if it was formed from broken coral, algae, mollusks, and Foraminifera, has been transported out to sea.

The beach sands were grouped into those collected on the windward sides of the islets, and those from the lee sides. It was found that median, sorting coefficient, and skewness of the windward and lee beach material was:

	Median	Sorting coefficient	Skewness
Windward shore	1.27	1.66	+ 1.43
Leeward shore	.86	1.54	+ 1.07

Wear and rounding of grains

The beach materials are homogenous in composition but not in shape or in specific gravity. Mineralogically the organisms consist of calcite or aragonite. The hardness of calcite is 3; that of aragonite, 3.5-4. The specific gravity of calcite is 2.71, that of aragonite, 2.94. Most organisms have internal cavities and some, such as Foraminifera and Halimeda, have porous walls. This porosity reduces the specific gravity. Emery and others (1954, p. 65) give the following specific gravities for beach material on Bikini: coral, 2.51-2.62; Calcarina sp., 2.11-2.46; Marginopora sp., 2.10-2.31, Halimeda sp., debris, 2.47. The beach sand has a specific gravity of 2.57. In sea water the specific gravity of the constituents was lower, an average figure for Halimeda debris being 1.77, and for the sand, 1.79. The comminuted fragments have a higher specific gravity than the whole organisms because of removal of pore space. Coral fragments have the lowest porosity of the contributing material to beaches, and hence have the highest specific gravity.

The coarser fractions of the beach materials are generally rounded (pl. 28), but it is difficult to assess the amount of abrasion that has occurred because of the heterogenous original shapes. The constituents are described as rounded if original protuberances have been removed by abrasion, and if the grains have smooth, worn surfaces.

The original calcareous skeletons give the initial shape to the material in the same way that the presence of certain organisms influences sorting and skewness. The shapes are modified by abrasion, partly by grinding of one fragment on another, and partly by splitting and breaking. Pebbles and cobbles of rocks such as limestone, sandstone, and shale, when they become rounded by abrasion, always retain some features of their original shape, which in turn are conducive to the final shape (Raleigh, 1942). Some forms, the corals and algae, are massive, whereas others, the shells and Foraminifera, are hollow and will tend to be less abraded than the heavier, massive forms, when subjected to the same amount of wear. However, the massive forms are more susceptible to breakage, although shells and Foraminifera are abraded on a beach.

Five stages in the abrasion and rounding of the principal Foraminifer, Calcarina spengleri, in the sands of the Northern Marshall Islands, have been established as a result of observation. The forms are illustrated in Plate 31. The Calcarinas shown on Plate 31 E and F indicate that the sand in which they occur has been subjected to long-continued abrasion on a beach.

Stages in abrasion resulting in rounding are not as easily defined for the corals and algae, although in general the fragments considered to be well worn, particularly coral fragments, can be recognized by their lack of protuberances. These protuberances are commonly more massive than those of Calcarina sp., just as the corals themselves are originally broken into larger fragments than the Calcarina, which are concentrated in the 2-1 and 1-0.5 mm grades as shown in figures 5-15. The larger size of the coral and algae has two effects as far as abrasion is concerned: (1), such fragments cannot be transported as far as lighter fragments with the same current and wave activity; and (2), when washed up and down on a beach by waves they will, because of their weight and massive nature, be rubbed together more. In other words, once they reach a beach and remain in a wave zone their abrasion must be relatively rapid. Algae may differ from corals in abrasion effects, because some of the algae are originally smooth and rounded in appearance (except Halimeda sp., which is bladelike and hollow). Some calcareous algae are softer than coral. Hence, well-rounded algae may have undergone a lesser amount of abrasion than corals having irregularities of surface.

Shells both of pelecypods and gastropods are not a very prominent feature of these beach sands, but they too have been abraded and rounded, the pelecypods more than the gastropods, although the latter, being hollow and more buoyant, generally show more fracturing than rounding.

As both calcite and aragonite have good cleavage, one of the results of breaking up of the reef organisms may be the production of angular fragments. Halimeda sp., which consists of aragonite, breaks up into innumerable small laths of aragonite. Corals formed of aragonite may split into angular pieces, which can then be abraded by rolling.

Another feature exhibited by some of the beach sands is a high polish that has been attained, it is presumed, by long-sustained rolling abrasion in a wave zone. Such sands are generally well sorted and the elimination of very fine grains has allowed the larger fragments to rub one against another. Size is a factor in the production of this polish, as well sorted sands are more polished than those that contain both large and small grains. Plate 28 shows polish in some of the beach materials. Sample 115 (Fosberg) from Wotho is a very coarse sand that shows high polish.

Legends of plates

Plate 28. Beach sand, appearance of material in the 2-4 mm grade. Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by H. C.Starkey, U.S. Geological Survey.

Plate 29. Beach sand, appearance of material in the 1-2 mm grade. Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by Starkey, U.S. Geological Survey.

Plate 30. Beach sand, appearance of material in the 0.5-1 mm grade(A), 0.25-0.5 mm grade (B) and 0.12-0.25 mm grade (C). Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by Starkey, U.S. Geological Survey.

Plate 31. *Calcarina* sp. showing various stages of abrasion in beach sands. Photo by Starkey, U.S. Geological Survey.

A. Spines intact, and the Foraminifer has not been abraded; this indicates little movement from site of origin. Specimen collected by J. I. Tracey, Jr., from reef flat at south end of Ifaluk islet, Ifaluk Atoll, Caroline Islands.

B. Many of the spines have been broken off. In beach sand from Taka Atoll (Tw 4), collected by MacNeil.

C. Nearly all the spines have been broken off, but a few still remain and are about one-half their original length. In beach sand from Taka Atoll (Tw 4) collected by MacNeil.

D. Only the stumps of the spines remain and there is some abrasion of the test of the Foraminifera. In beach sand from Taka Atoll (Tw 4) collected by MacNeil.

E. F. Only the test of the Foraminifer remains, and it is well polished; all the spines have been completely removed and the test has been reduced in size, but the chambers have not been exposed. In beach sand from Wotho Atoll collected by MacNeil.

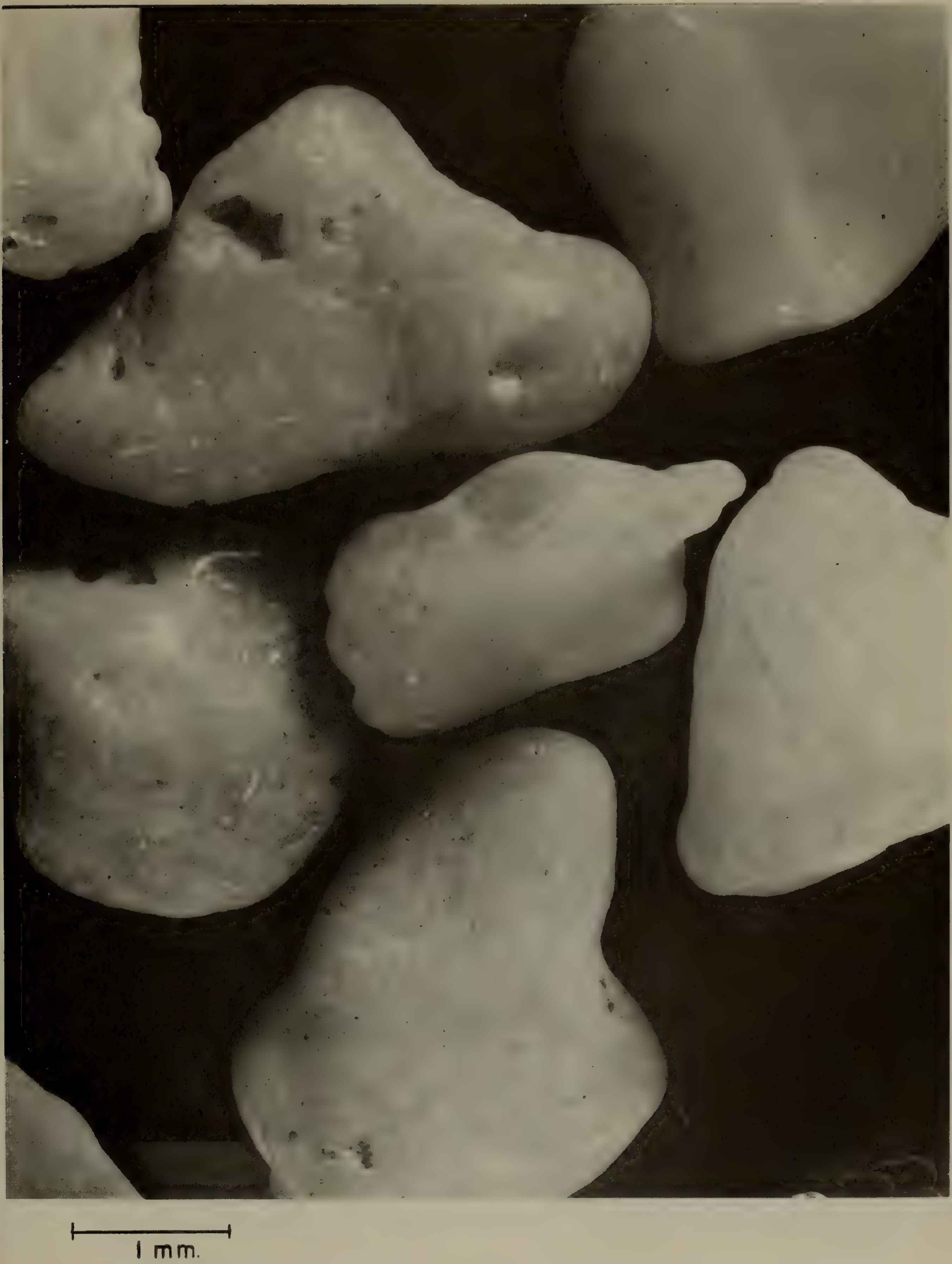

1 mm.

Plate 29

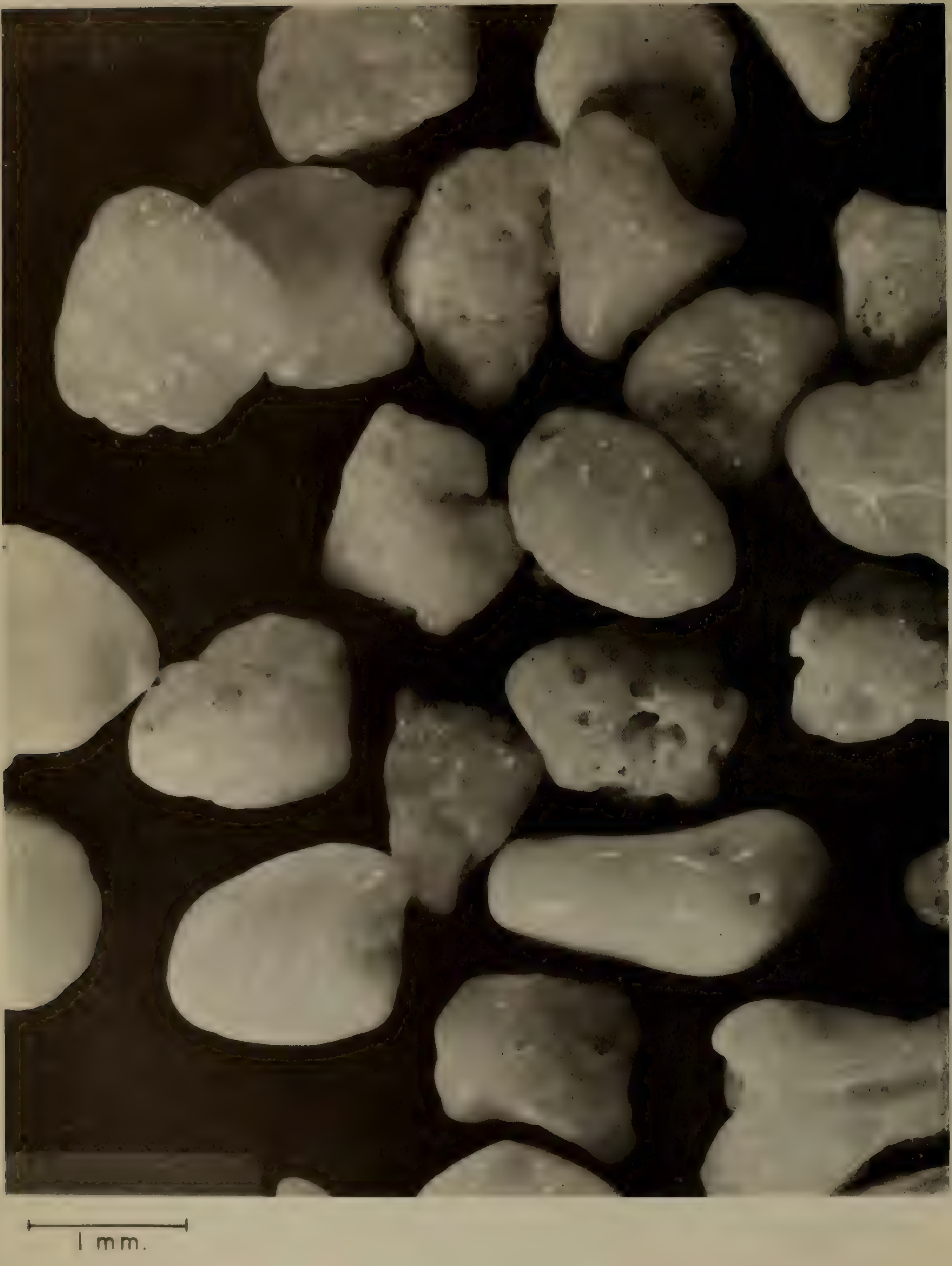
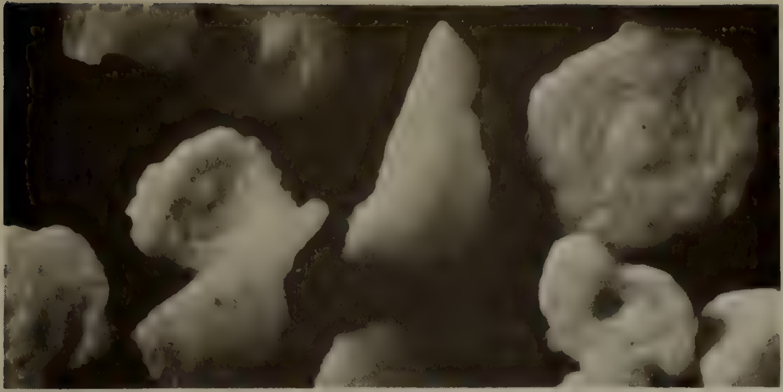
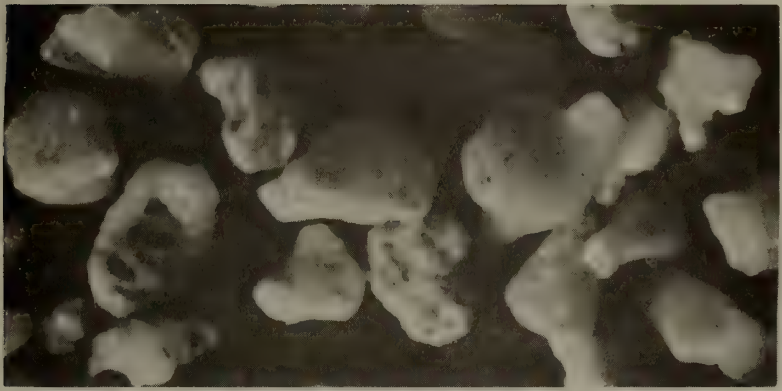


Plate 30

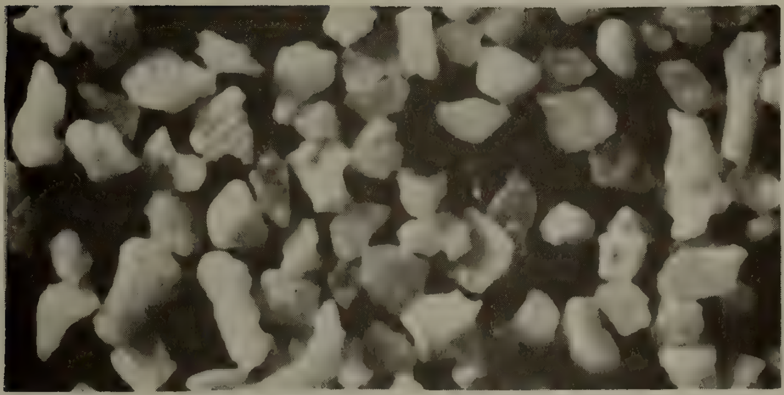
A

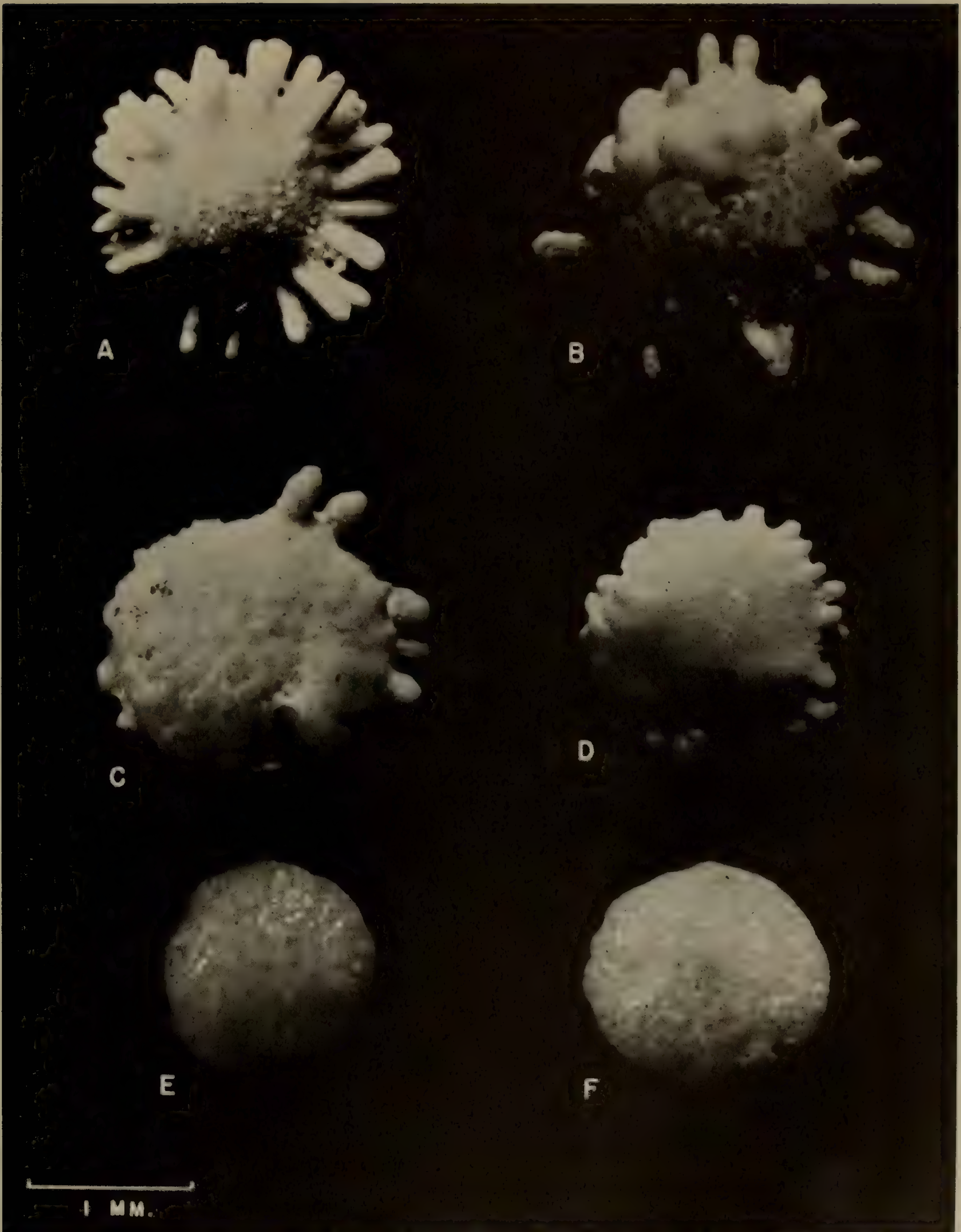


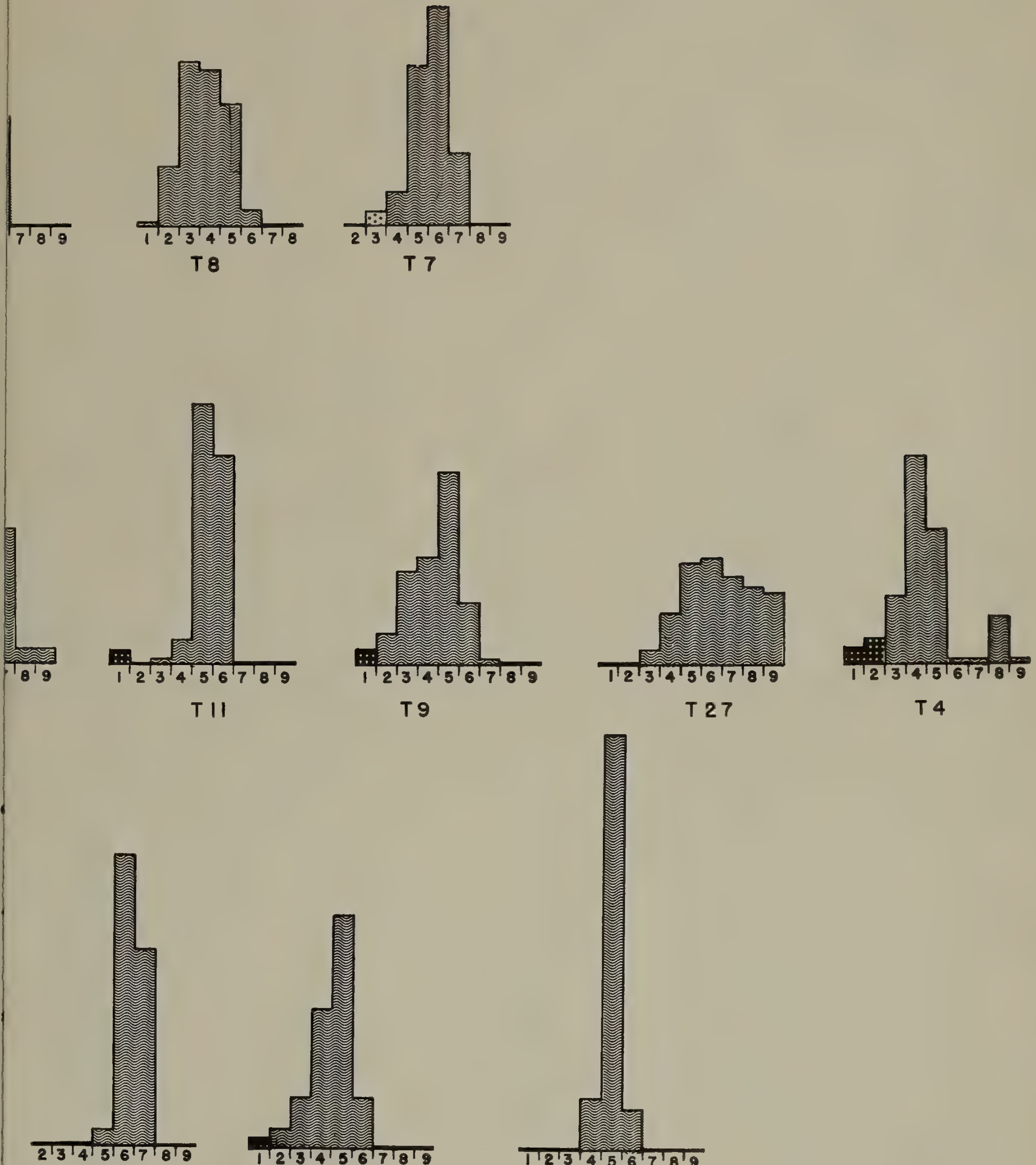
B



C




A
B
C
D
E
F
1 MM.



SANDS

FIGURE 6. BIKAR ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

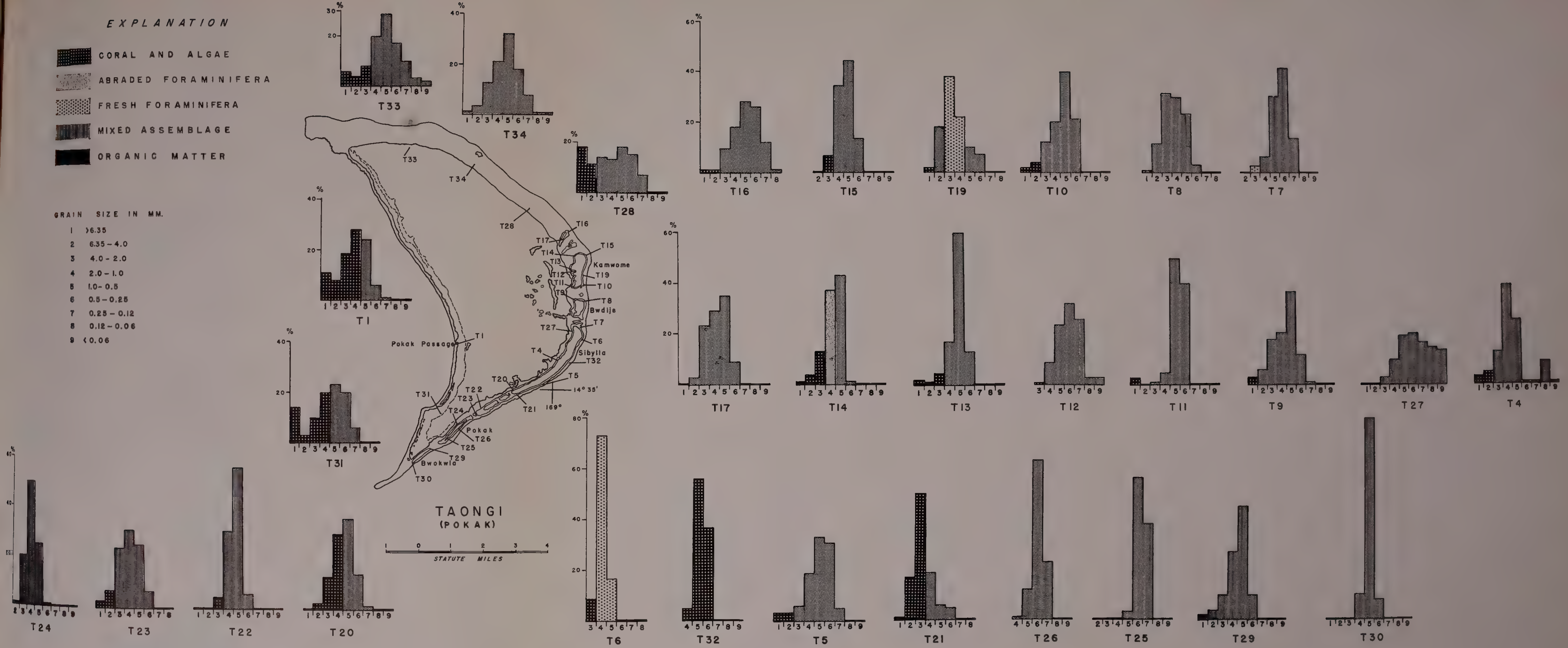


FIGURE 5. TAONGI (POKAK) ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

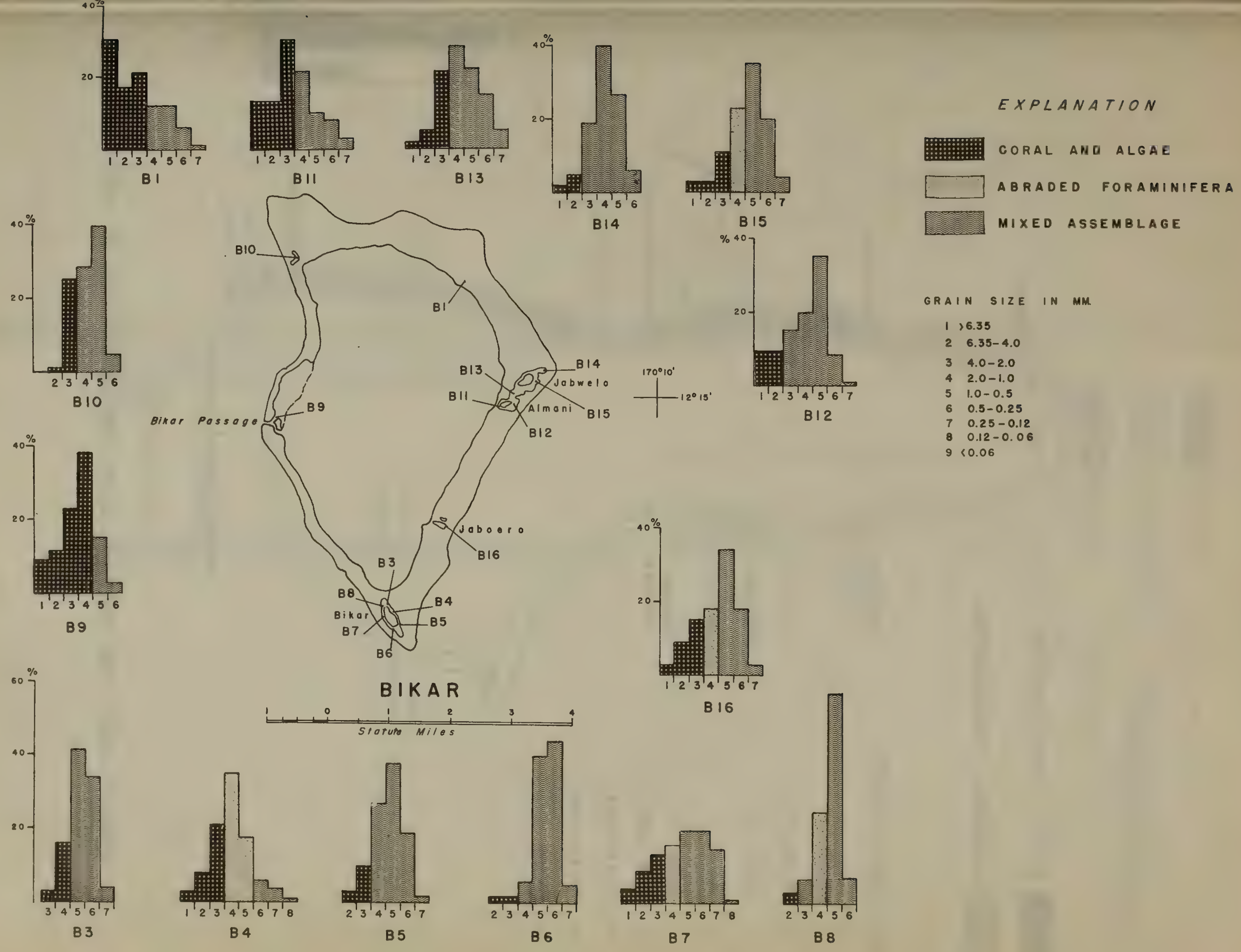


FIGURE 6. BIKAR ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

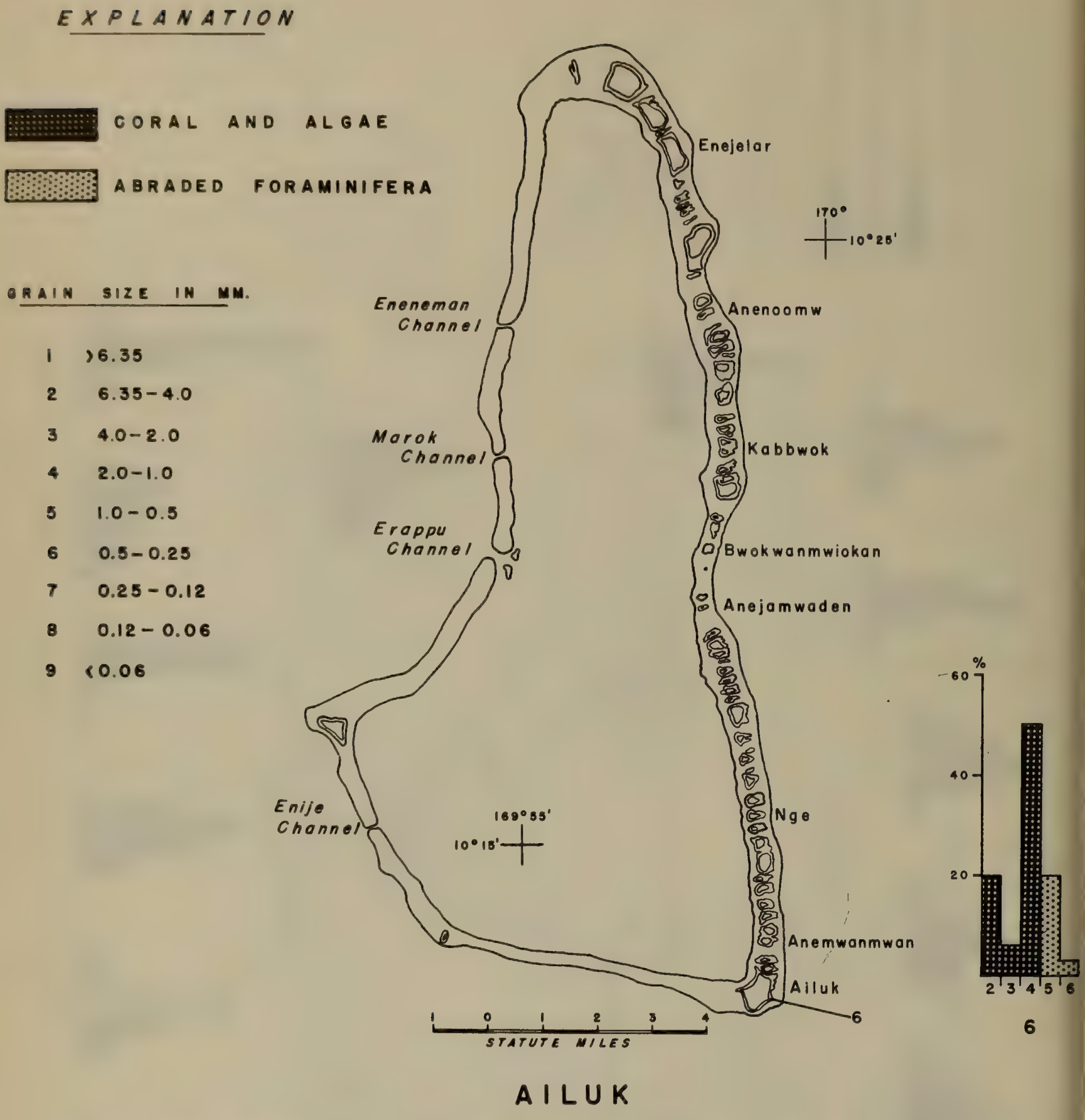

EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
GRAIN SIZE IN MM.
1 >6.35
2 6.35 – 4.0
3 4.0 – 2.0
4 2.0 – 1.0
5 1.0 – 0.5
6 0.5 – 0.25
7 0.25 – 0.12
8 0.12 – 0.06
9 <0.06
Enejelar
170°
10°25'
Eneneman Channel
Anenoomw
Kabbwok
Marok Channel
Erappu Channel
Bwokwanmwiokan
Anejamwaden
Nge
Enije Channel
169°55'
10°15'
Anemwanmwan
Ailuk
6
1 0 1 2 3 4
STATUTE MILES
%
60
40
20
2 3 4 5 6
6
AILUK

FIGURE 7. AILUK ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

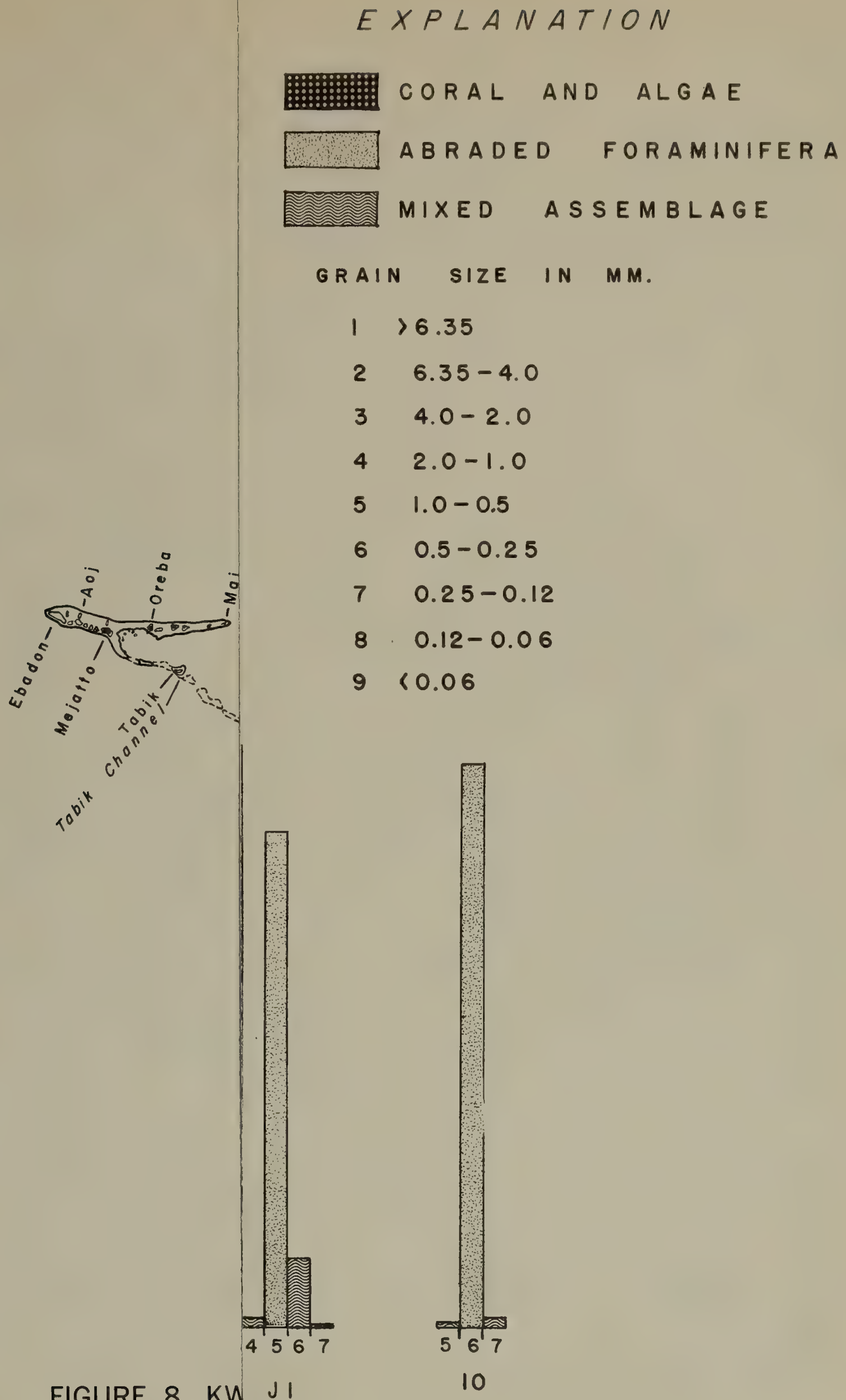


FIGURE 8. KW
OF

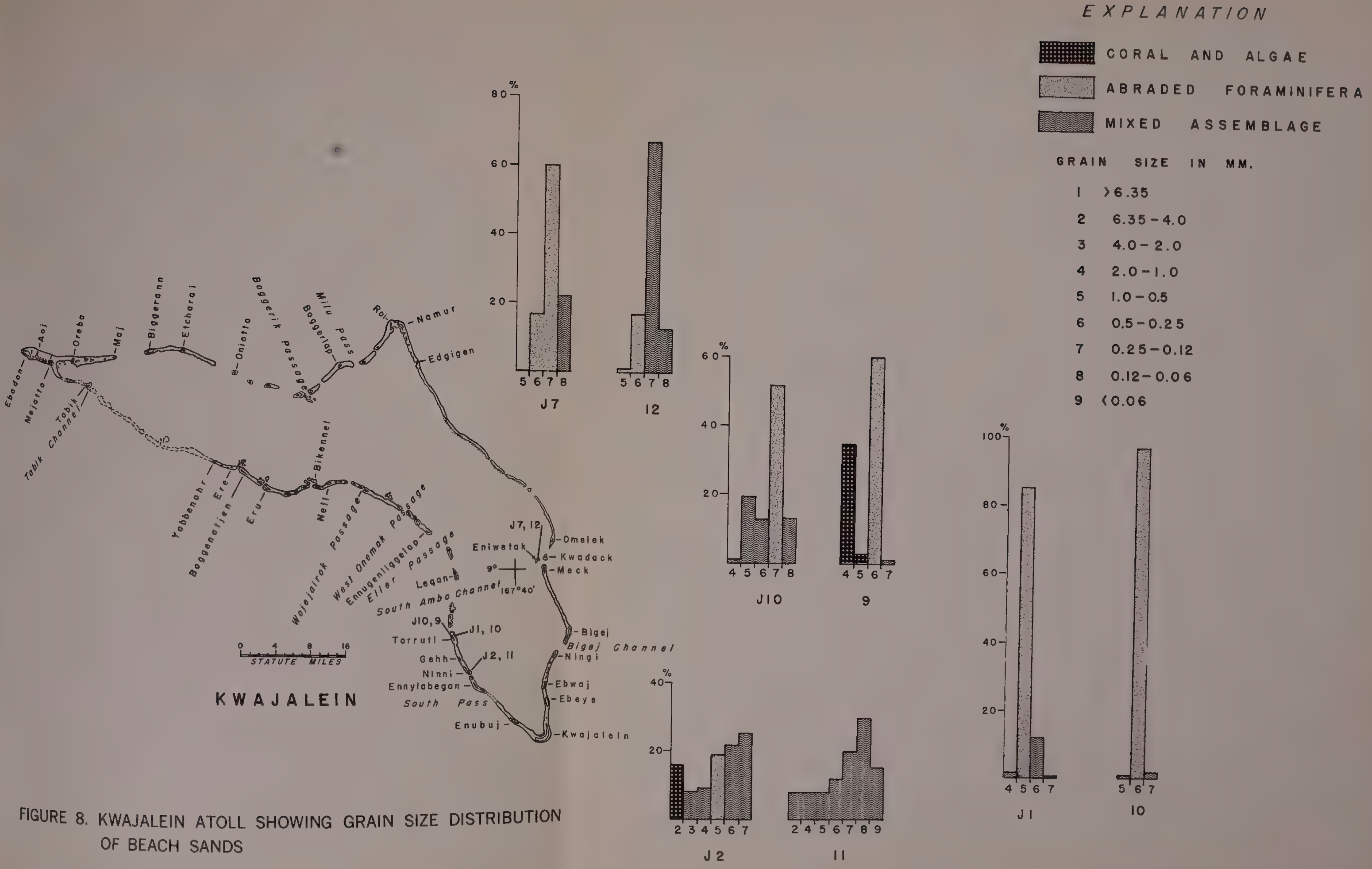

EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35-4.0
3 4.0-2.0
4 2.0-1.0
5 1.0-0.5
6 0.5-0.25
7 0.25-0.12
8 0.12-0.06
9 <0.06
%
80
60
40
20
5 6 7 8
J7
5 6 7 8
12
%
60
40
20
4 5 6 7 8
J10
4 5 6 7
9
%
100
80
60
40
20
4 5 6 7
J1
5 6 7
10
%
40
20
2 3 4 5 6 7
J2
2 4 5 6 7 8 9
11
Ebadon
Majatto
Aoj
Oreba
Maj
Biggerann
Etcharai
Oniotto
Boggerik Passage
Boggerlap
Mlju Pass
Roi-Namur
Edgigen
Tabik
Tabik Channel
Yabbenohr
Ere
Boggenaltjen
Eru
Bikennel
Nell
Passage
West Onemak Passage
Wojejairok
Ennugenliggelap
Eller passage
Legan
South Ambo Channel
J7, 12
Eniwetak
Omelek
Kwadack
Meck
9°
167°40'
J10, 9
J1, 10
Torruti
Gehh
J2, 11
Ninni
Ennylabegan
South Pass
Enubuj
Kwajalein
Ebeye
Ebwaj
Ningi
Bigej
Bigej Channel
0 4 8 16
STATUTE MILES
KWAJALEIN

FIGURE 8. KWAJALEIN ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

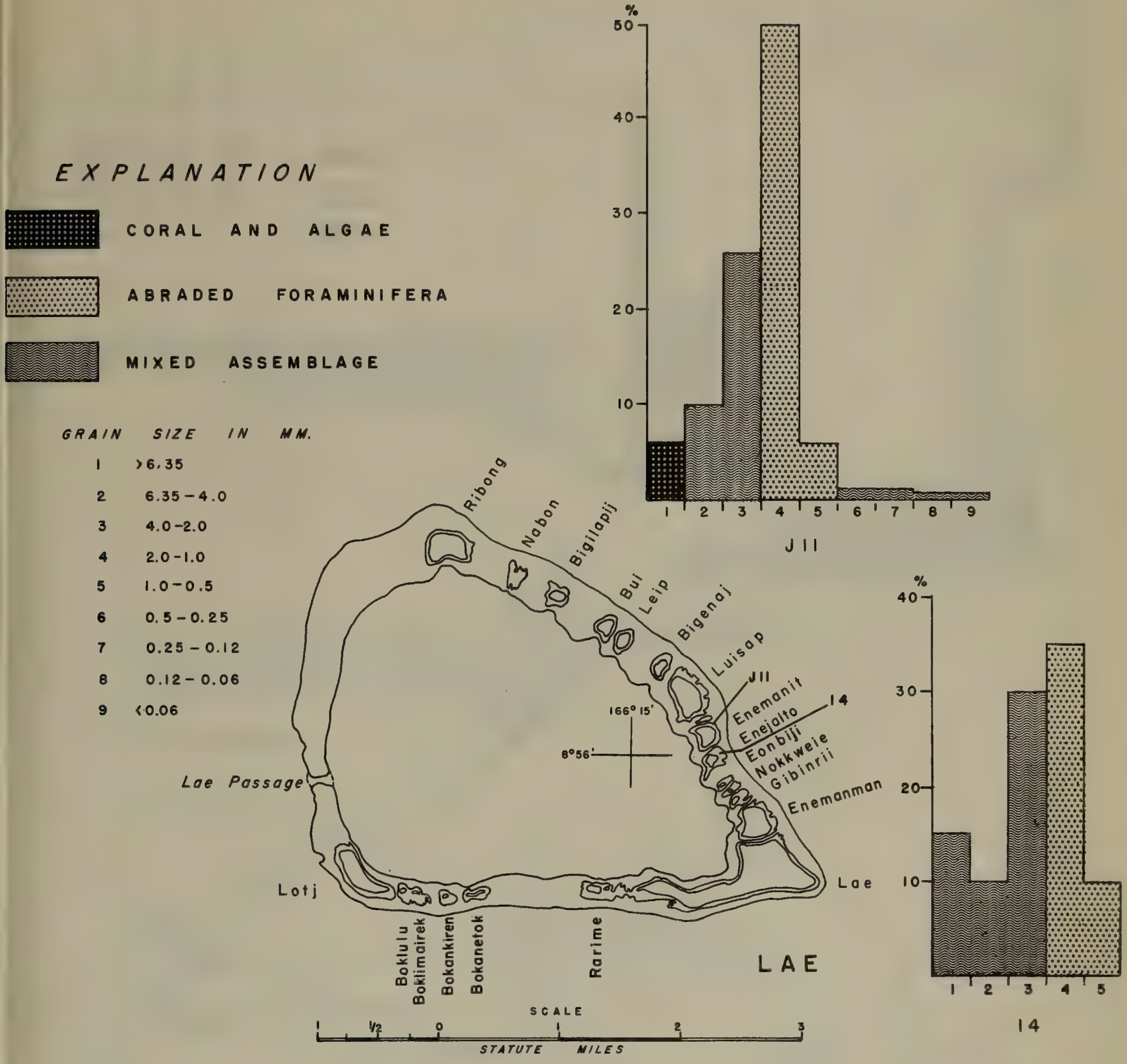

EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35 - 4.0
3 4.0 - 2.0
4 2.0 - 1.0
5 1.0 - 0.5
6 0.5 - 0.25
7 0.25 - 0.12
8 0.12 - 0.06
9 <0.06
%
50
40
30
20
10
1 2 3 4 5 6 7 8 9
J11
%
40
30
20
10
1 2 3 4 5
14
Ribong
Nabon
Bigilapij
Bui
Leip
Bigenaj
Luisap
J11
Enemanit
Enejalto
14
Eonbiji
Nokkweie
Gibinrii
Enemanman
166° 15'
8°56'
Lae Passage
Lotj
Lae
Boklulu
Boklimairek
Bokankiren
Bokanetok
Rarime
LAE
SCALE
1 1/2 0 1 2 3
STATUTE MILES

FIGURE 9. LAE ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

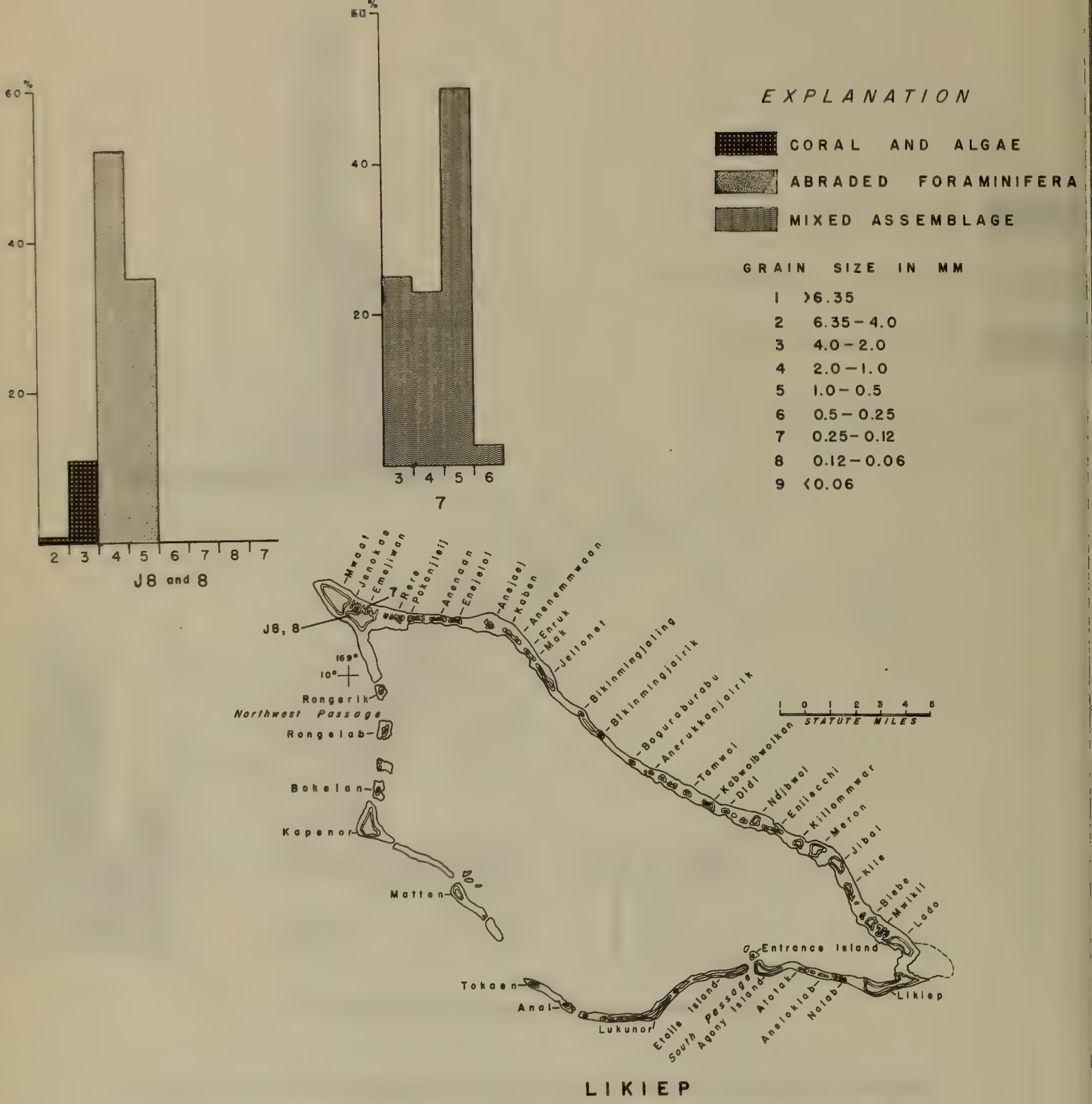

%
60
40
20
2
3
4
5
6
7
8
7
J8 and 8
%
60
40
20
3
4
5
6
7
EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
MIXED ASSEMBLAGE
GRAIN SIZE IN MM
1 >6.35
2 6.35 – 4.0
3 4.0 – 2.0
4 2.0 – 1.0
5 1.0 – 0.5
6 0.5 – 0.25
7 0.25 – 0.12
8 0.12 – 0.06
9 <0.06
Mwaat
Janokae
Emejiwan
7
Rere
Pokonjileij
Anenaan
Enejelol
Anejael
Kaben
Anenemmwaan
Enruk
Mak
Jeltonet
J8, 8
169°
10°
Rongerik
Northwest Passage
Rongelab
Bokelan
Kapenor
Matten
Bikinmingjaling
Bikinmingjairik
Boguraburabu
Anerukkanjairik
Tamwoi
Kabwolbwolkan
Didi
Ndjbwol
Eniiecchi
Killommwar
Meron
Jibal
Kile
Biebe
Mwikil
Lado
1 0 1 2 3 4 5
STATUTE MILES
Entrance Island
Tokaen
Anal
Lukunor
Etoile Island
South passage
Agony Island
Atotak
Aneloklab
Nalab
Likiep
LIKIEP

FIGURE 10. LIKIEP ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

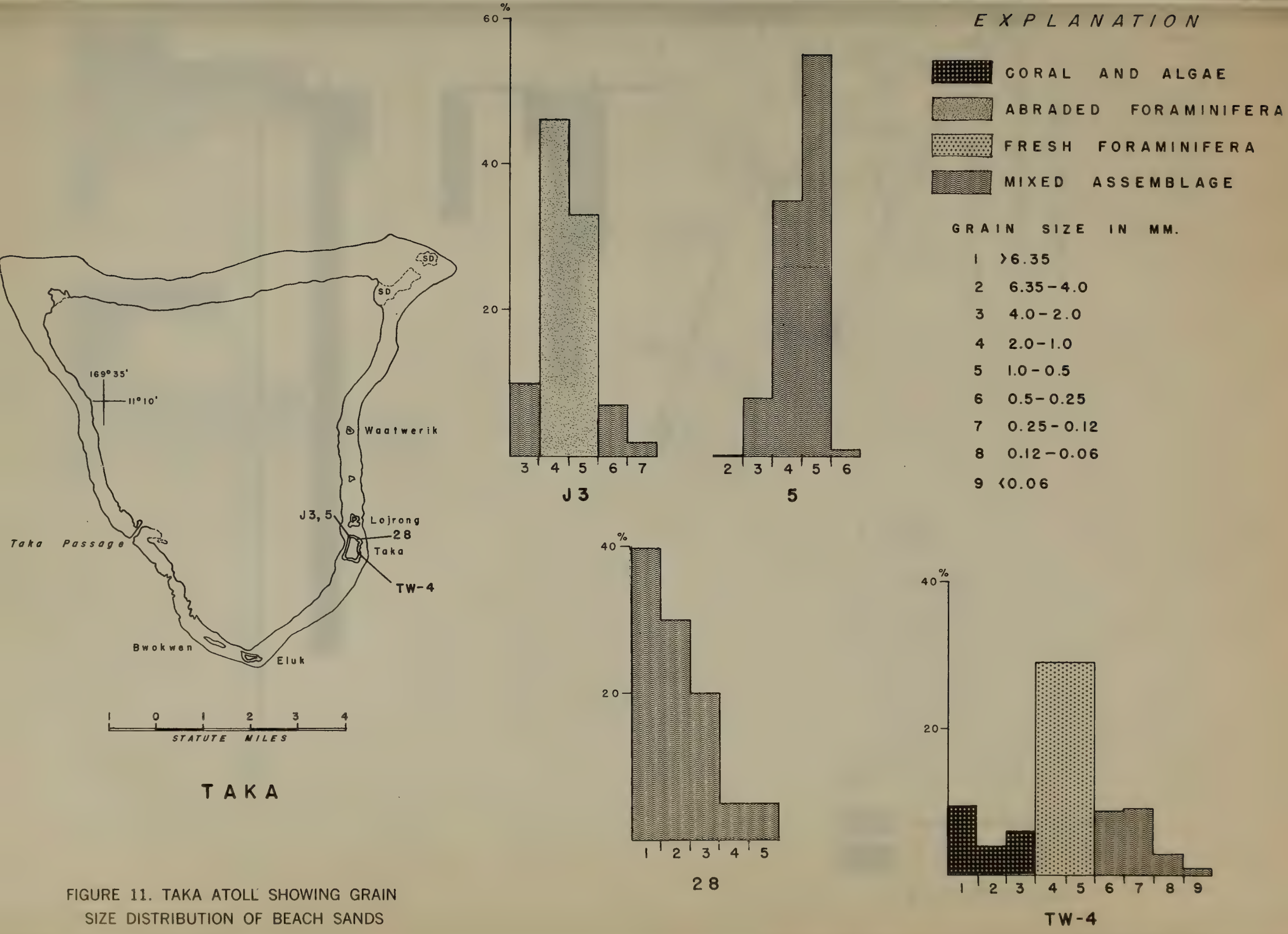
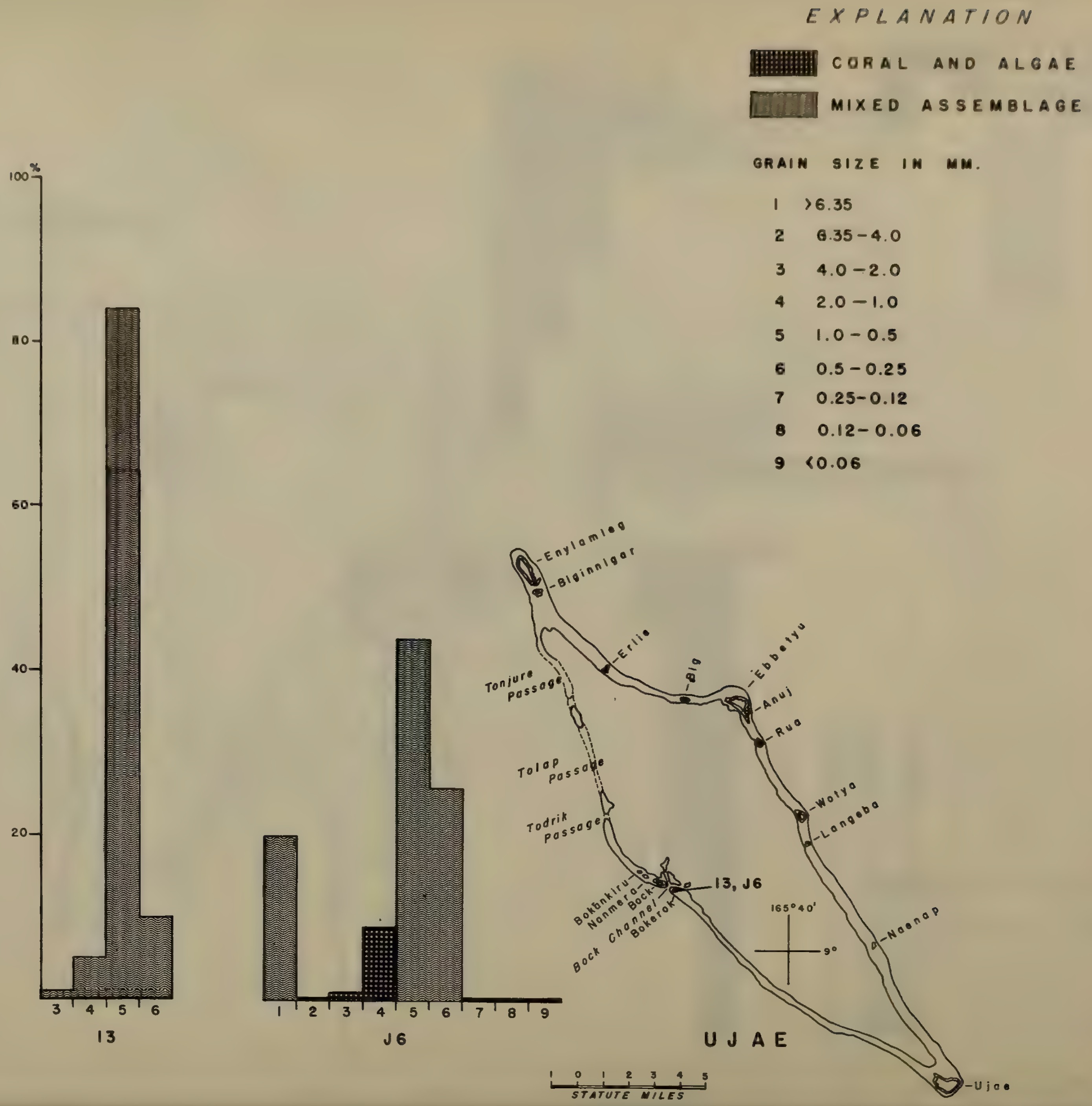
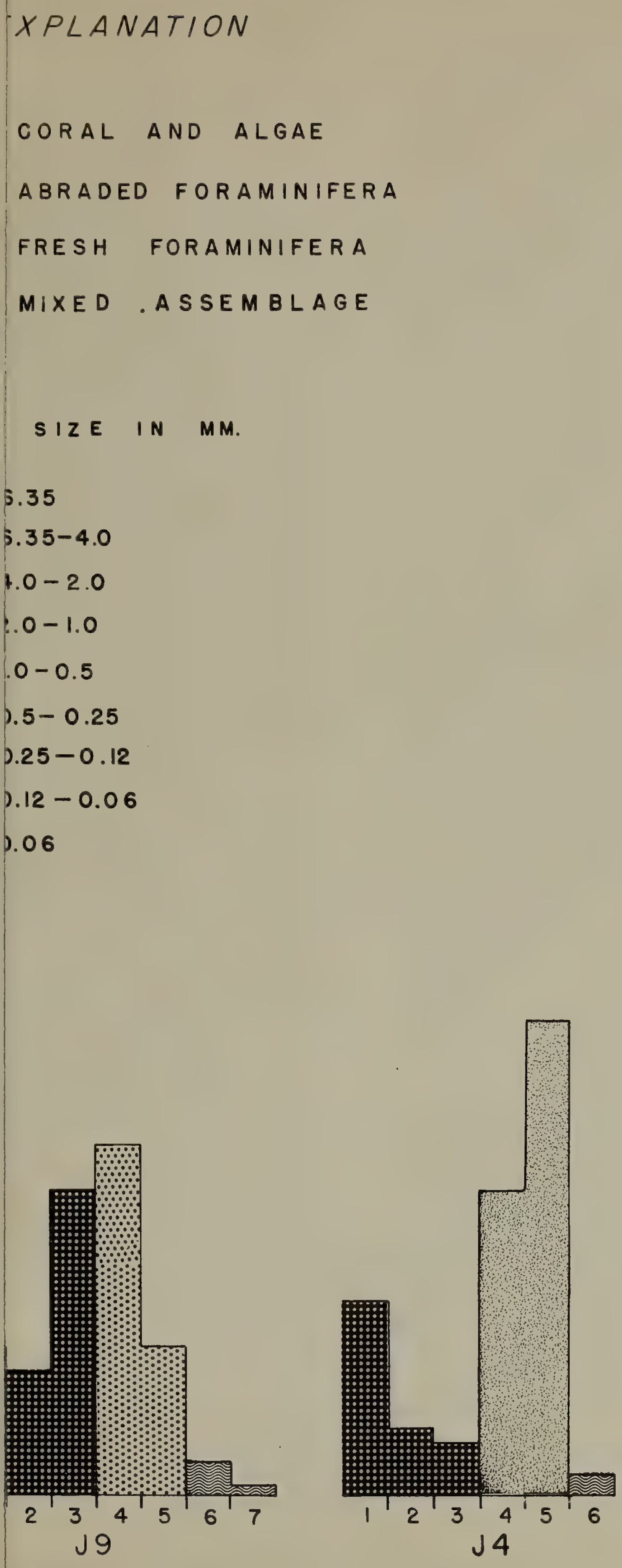


FIGURE 11. TAKA ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS


EXPLANATION
CORAL AND ALGAE
MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35-4.0
3 4.0-2.0
4 2.0-1.0
5 1.0-0.5
6 0.5-0.25
7 0.25-0.12
8 0.12-0.06
9 <0.06
100 %
80
60
40
20
3 4 5 6
13
1 2 3 4 5 6 7 8 9
J6
Enylamieg
Biginnigar
Erlie
Big
Ebbetyu
Anuj
Rua
Wotya
Langeba
Naenap
Ujae
Tonjure Passage
Tolap Passage
Todrik Passage
Bokbnkiru
Nanmera
Bock
Bock Channel
Bokerok
13, J6
165°40'
9°
UJAE
1 0 1 2 3 4 5
STATUTE MILES


XPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED .ASSEMBLAGE
SIZE IN MM.
.35
.35–4.0
.0 – 2.0
.0 – 1.0
.0 – 0.5
.5 – 0.25
.25 – 0.12
.12 – 0.06
.06
2
3
4
5
6
7
J9
1
2
3
4
5
6
J4

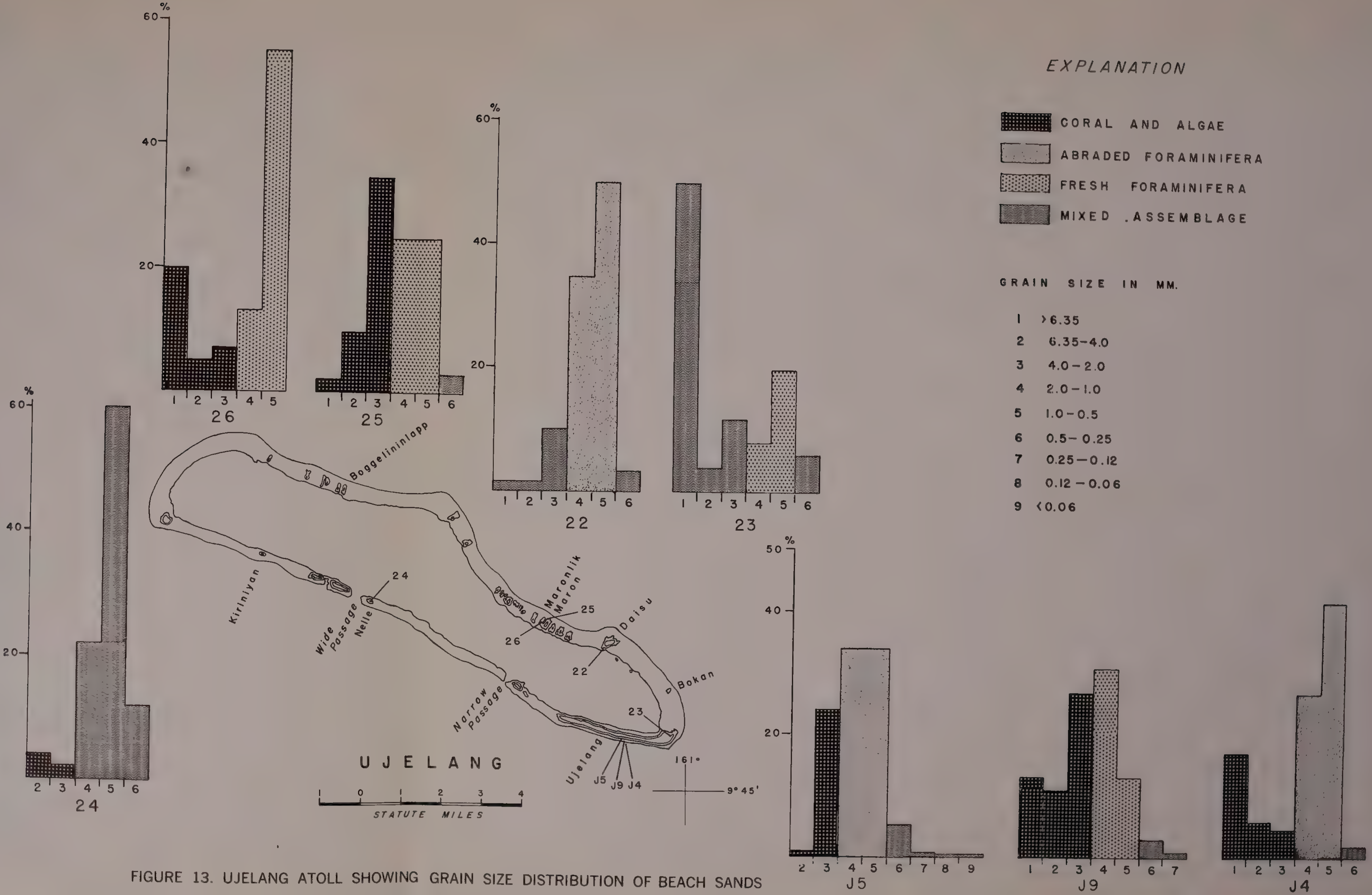


FIGURE 13. UJELANG ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

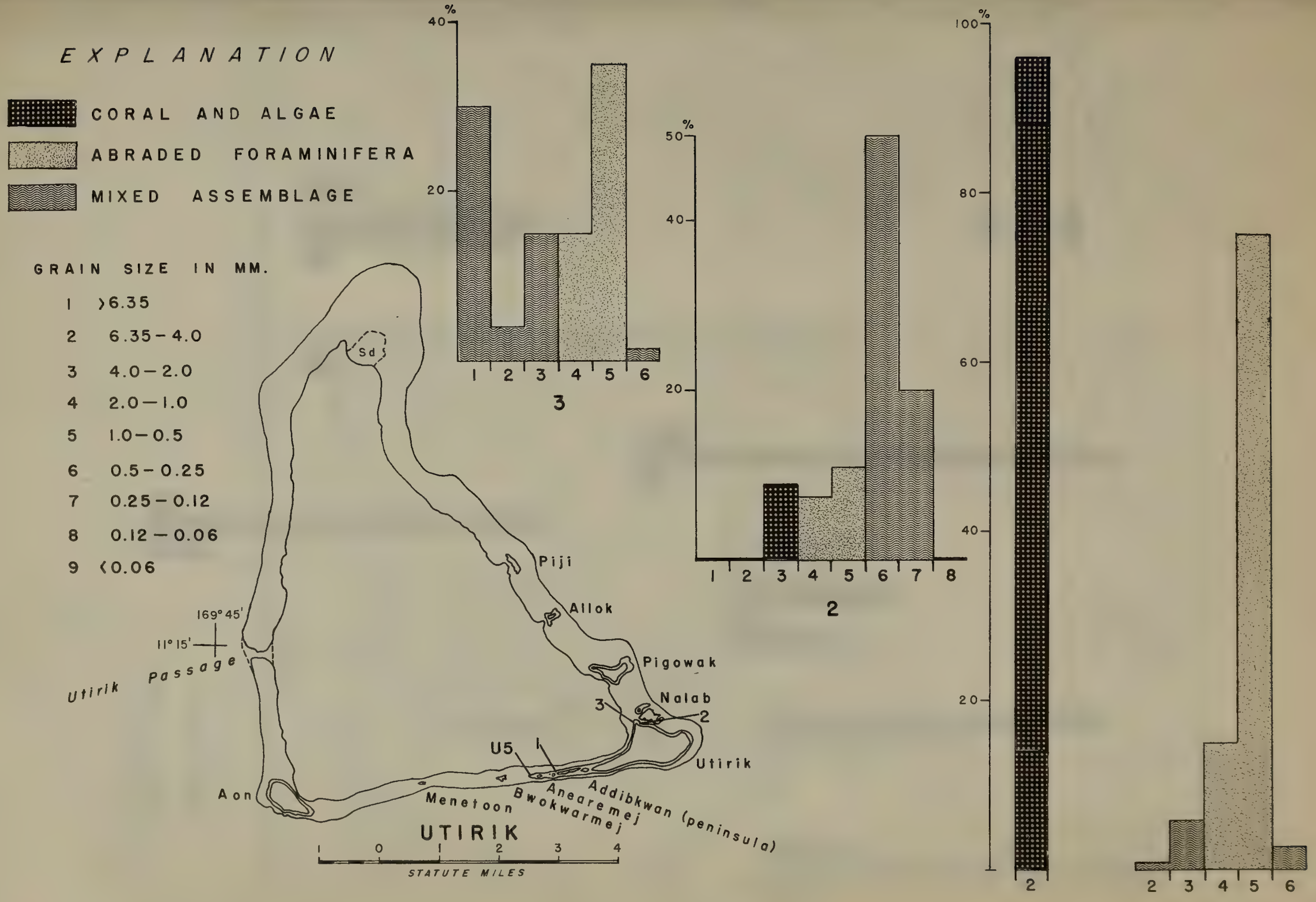

EXPLANATION
▩ CORAL AND ALGAE
▨ ABRADED FORAMINIFERA
▤ MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35 – 4.0
3 4.0 – 2.0
4 2.0 – 1.0
5 1.0 – 0.5
6 0.5 – 0.25
7 0.25 – 0.12
8 0.12 – 0.06
9 <0.06
%
40
20
1 2 3 4 5 6
3
%
50
40
20
1 2 3 4 5 6 7 8
2
%
100
80
60
40
20
2
U-5
2 3 4 5 6
1
Sd
Piji
Allok
Pigowak
Nalab
3
2
Utirik
U5
1
Addibkwan (peninsula)
Anearemej
Bwokwarmej
Menetoon
Aon
169° 45'
11° 15'
Utirik Passage
UTIRIK
1 0 1 2 3 4
STATUTE MILES

FIGURE 14. UTIRIK ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

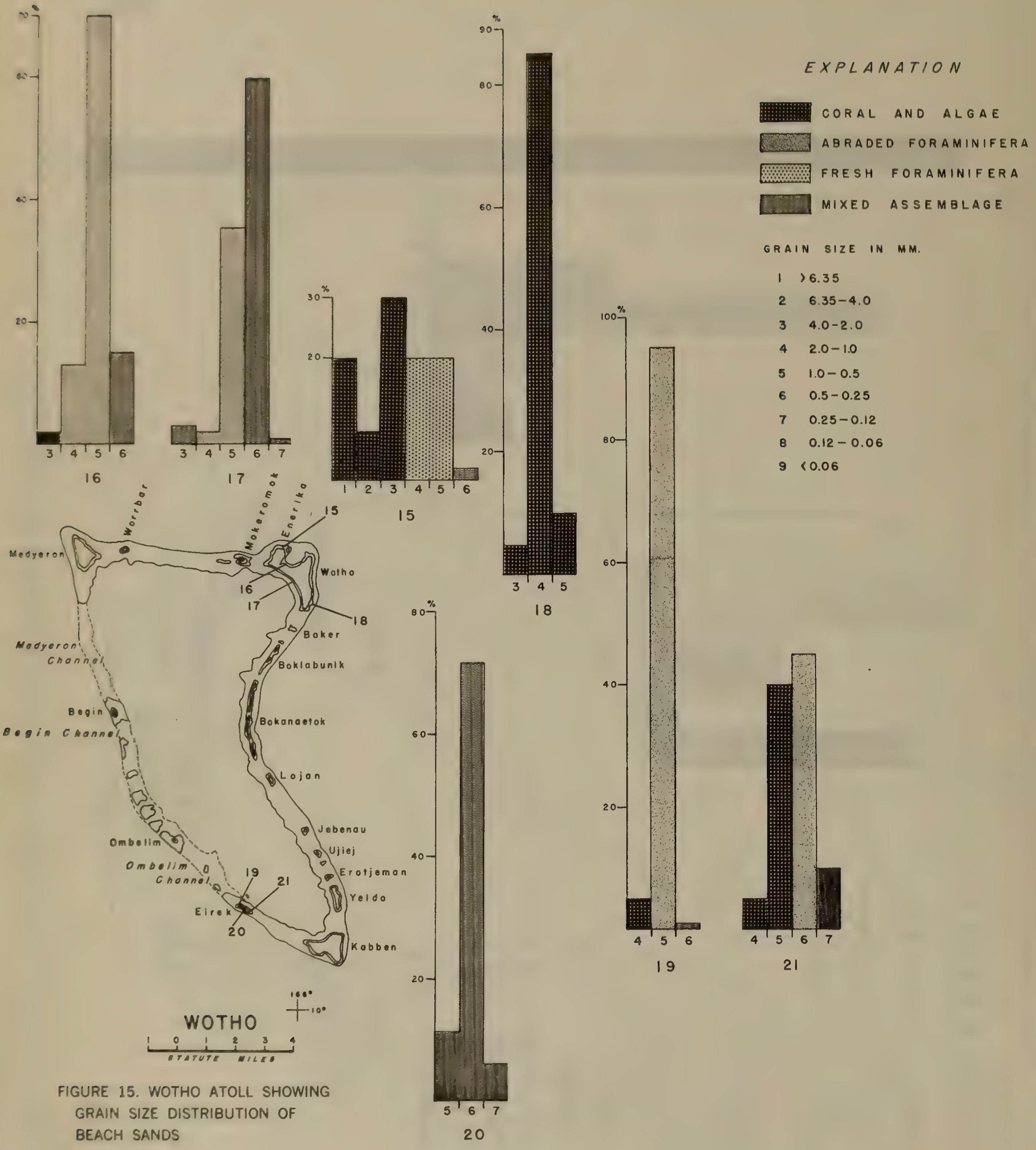


FIGURE 15. WOTHO ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

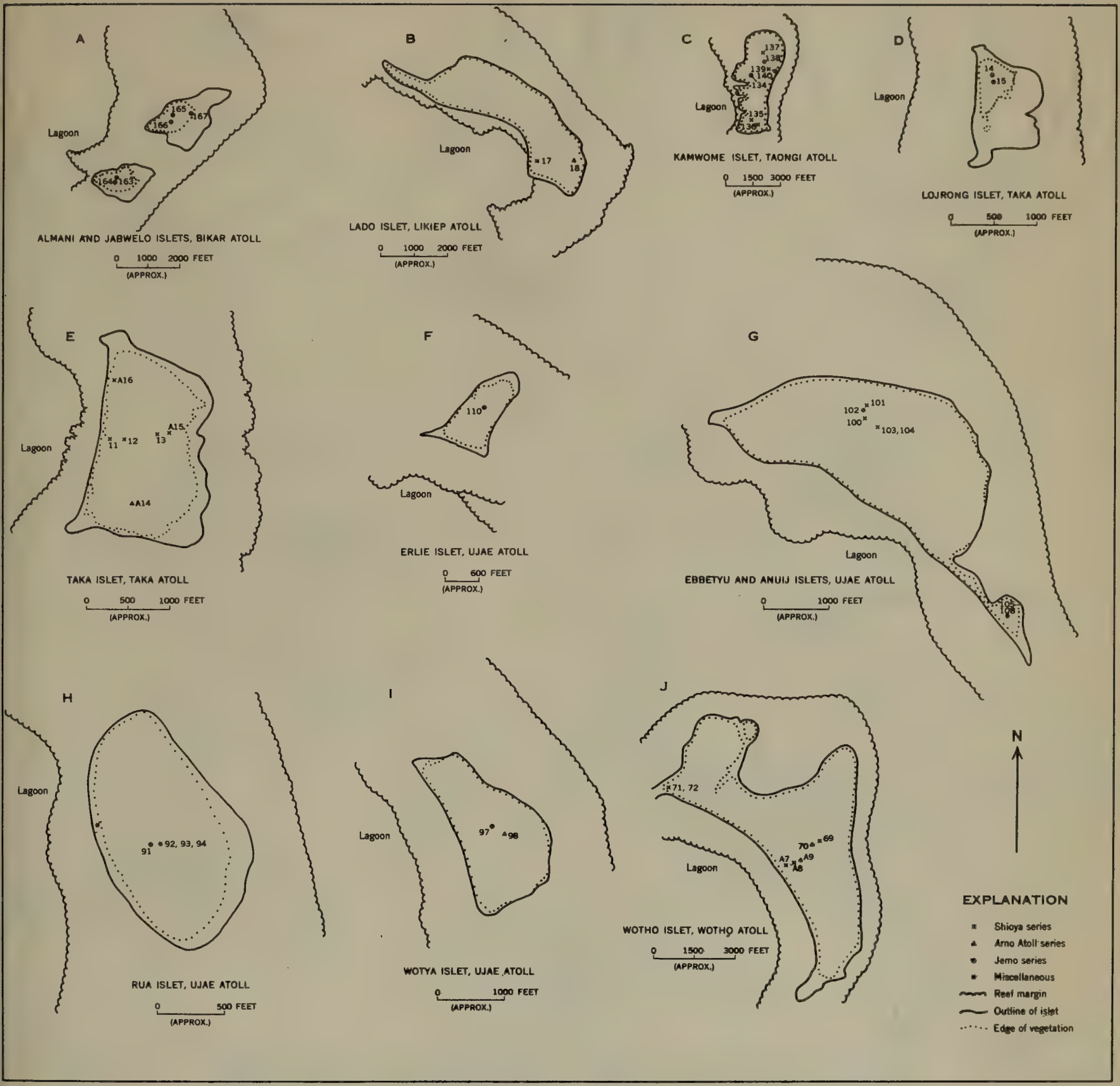

A
Lagoon
165
167
166
164
163
ALMANI AND JABWELO ISLETS, BIKAR ATOLL
0 1000 2000 FEET
(APPROX.)
B
Lagoon
17
18
LADO ISLET, LIKIEP ATOLL
0 1000 2000 FEET
(APPROX.)
C
137
138
139
140
134
135
136
Lagoon
KAMWOME ISLET, TAONGI ATOLL
0 1500 3000 FEET
(APPROX.)
D
Lagoon
14
15
LOJRONG ISLET, TAKA ATOLL
0 500 1000 FEET
(APPROX.)
E
A16
Lagoon
11
12
13
A15
A14
TAKA ISLET, TAKA ATOLL
0 500 1000 FEET
(APPROX.)
F
110
Lagoon
ERLIE ISLET, UJAE ATOLL
0 600 FEET
(APPROX.)
G
102
101
100
103, 104
Lagoon
105
106
EBBETYU AND ANUIJ ISLETS, UJAE ATOLL
0 1000 FEET
(APPROX.)
H
Lagoon
91
92, 93, 94
RUA ISLET, UJAE ATOLL
0 500 FEET
(APPROX.)
I
Lagoon
97
98
WOTYA ISLET, UJAE ATOLL
0 1000 FEET
(APPROX.)
J
71, 72
Lagoon
70
69
A7
A9
A8
WOTHO ISLET, WOTHO ATOLL
0 1500 3000 FEET
(APPROX.)
N
EXPLANATION
Shioya series
Arno Atoll series
Jemo series
Miscellaneous
Reef margin
Outline of islet
Edge of vegetation

FIGURE 16. MAPS OF WINDWARD ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED

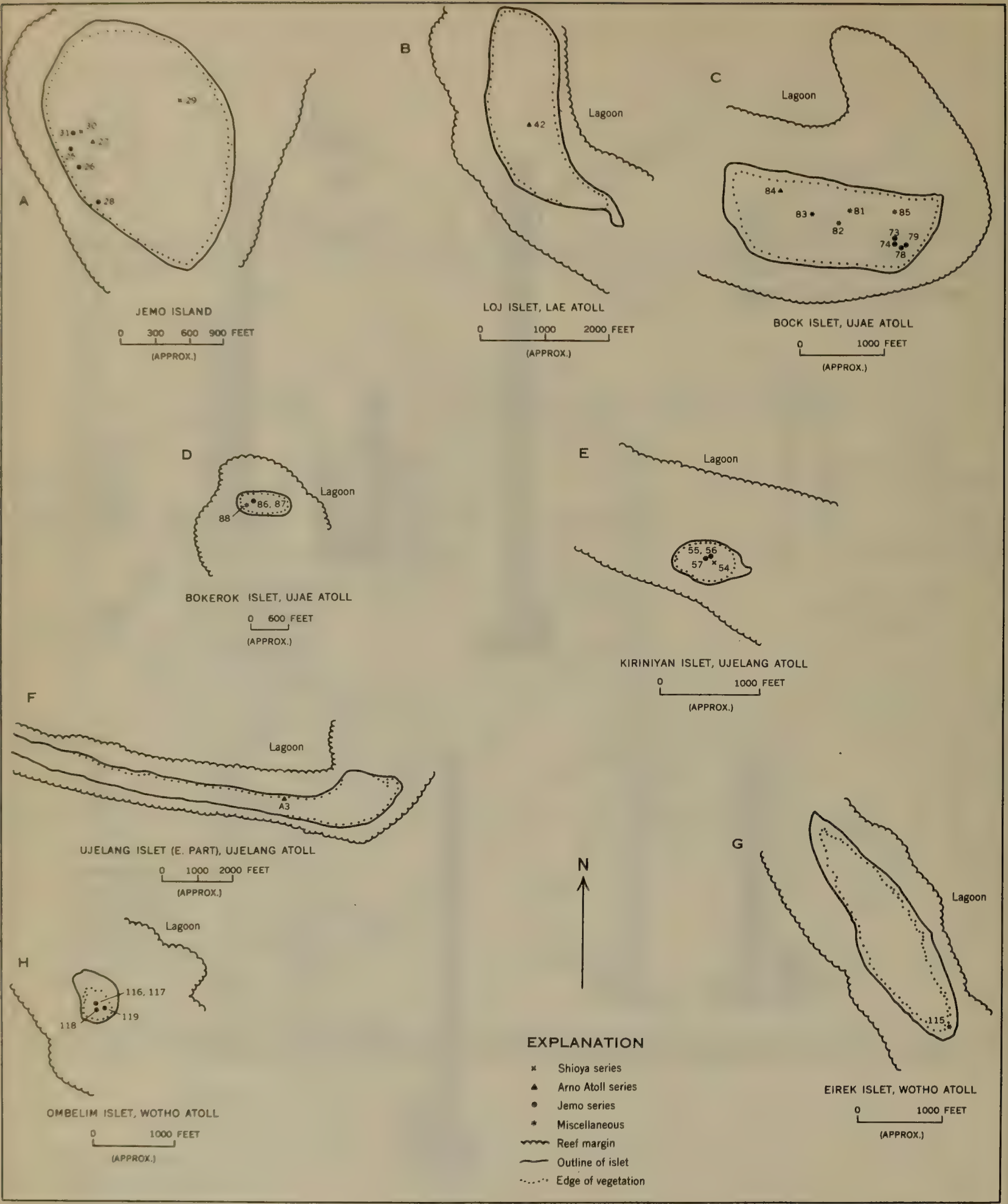

A
29
30
31
27
25
26
28
JEMO ISLAND
0 300 600 900 FEET
(APPROX.)
B
Lagoon
42
LOJ ISLET, LAE ATOLL
0 1000 2000 FEET
(APPROX.)
C
Lagoon
84
83
81
85
82
73
79
74
78
BOCK ISLET, UJAE ATOLL
0 1000 FEET
(APPROX.)
D
Lagoon
86, 87
88
BOKEROK ISLET, UJAE ATOLL
0 600 FEET
(APPROX.)
E
Lagoon
55, 56
57
54
KIRINIYAN ISLET, UJELANG ATOLL
0 1000 FEET
(APPROX.)
F
Lagoon
A3
UJELANG ISLET (E. PART), UJELANG ATOLL
0 1000 2000 FEET
(APPROX.)
G
Lagoon
115
EIREK ISLET, WOTHO ATOLL
0 1000 FEET
(APPROX.)
H
Lagoon
116, 117
119
118
OMBELIM ISLET, WOTHO ATOLL
0 1000 FEET
(APPROX.)
N
EXPLANATION
× Shioya series
▲ Arno Atoll series
● Jemo series
* Miscellaneous
Reef margin
Outline of islet
Edge of vegetation

FIGURE 17. MAPS OF LEEWARD ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED

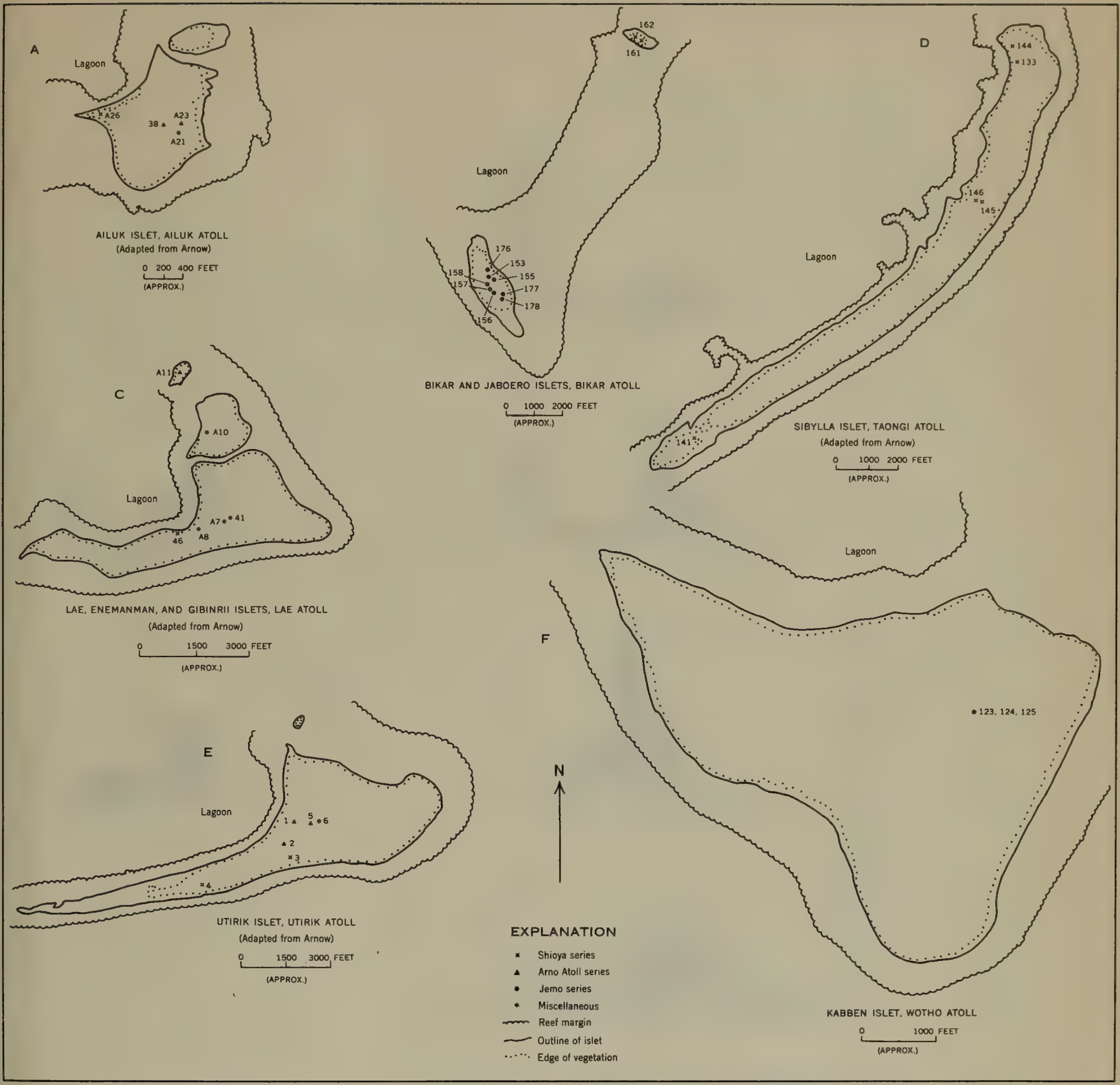
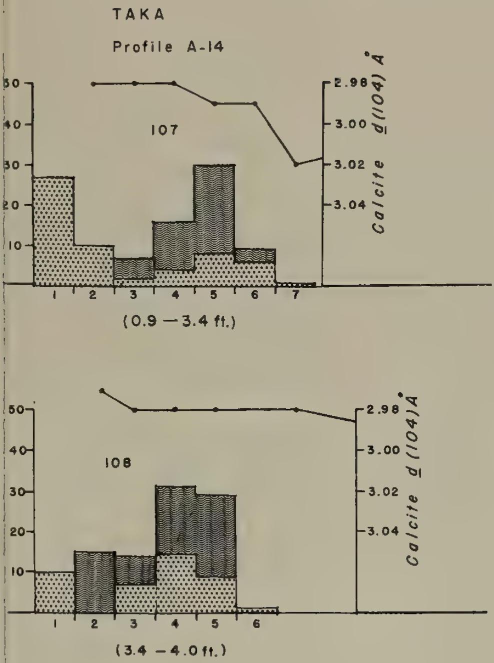

A
Lagoon
A26
38
A23
A21
AILUK ISLET, AILUK ATOLL
(Adapted from Arnow)
0 200 400 FEET
(APPROX.)
162
161
Lagoon
176
153
155
158
157
177
178
156
BIKAR AND JABOERO ISLETS, BIKAR ATOLL
0 1000 2000 FEET
(APPROX.)
D
144
133
146
145
Lagoon
141
SIBYLLA ISLET, TAONGI ATOLL
(Adapted from Arnow)
0 1000 2000 FEET
(APPROX.)
C
A11
A10
Lagoon
A7
41
46
A8
LAE, ENEMANMAN, AND GIBINRII ISLETS, LAE ATOLL
(Adapted from Arnow)
0 1500 3000 FEET
(APPROX.)
Lagoon
F
123, 124, 125
E
Lagoon
1
5
6
2
3
4
UTIRIK ISLET, UTIRIK ATOLL
(Adapted from Arnow)
0 1500 3000 FEET
(APPROX.)
N
EXPLANATION
× Shioya series
▲ Arno Atoll series
● Jemo series
* Miscellaneous
Reef margin
Outline of islet
Edge of vegetation
KABBEN ISLET, WOTHO ATOLL
0 1000 FEET
(APPROX.)

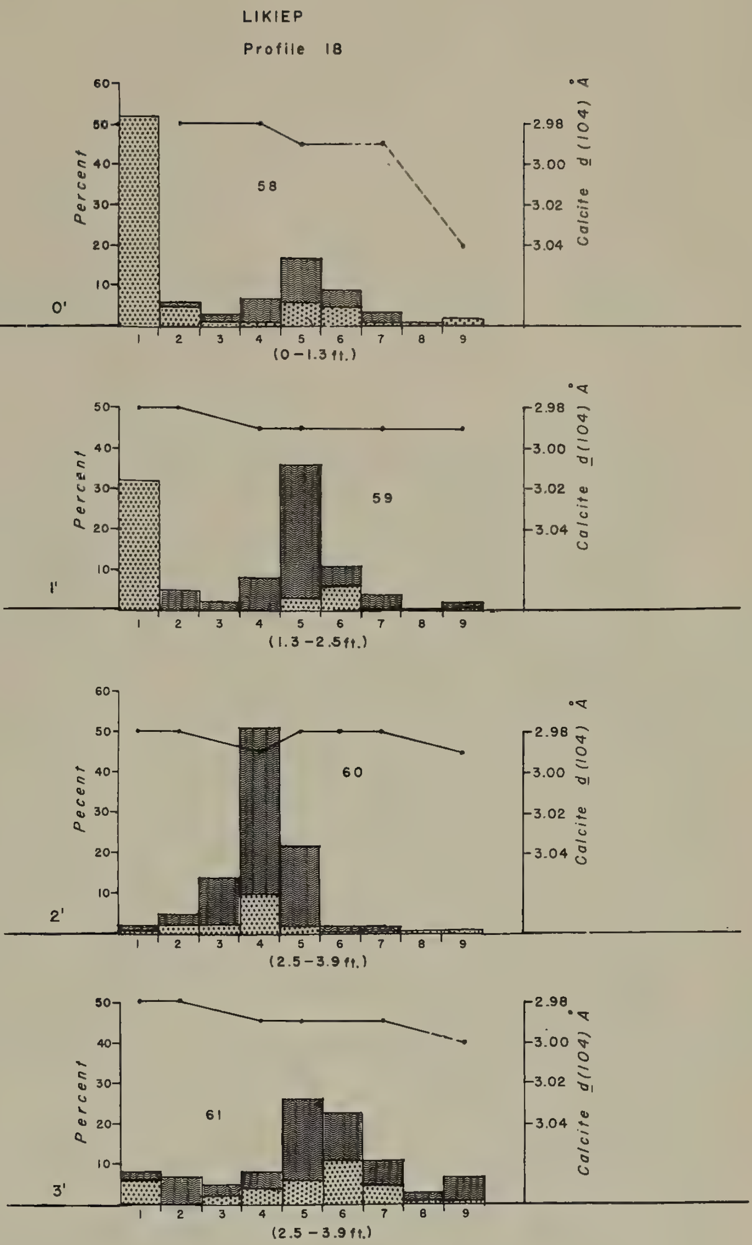
FIGURE 18. MAPS OF SOUTHEASTERN CORNER ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED



TAKA

Profile A-14

ARNO ATOLL SERIES



LIKIEP

Profile 18

ARNO ATOLL SERIES

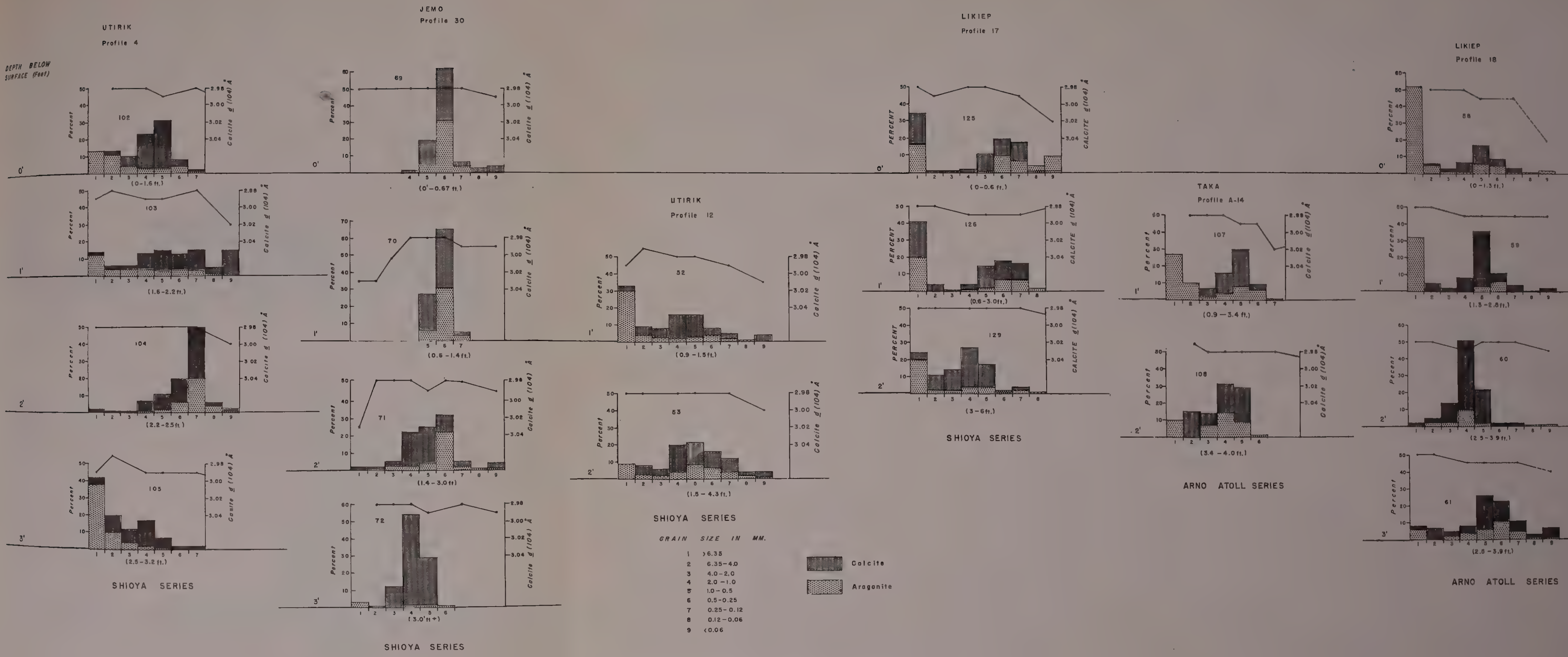
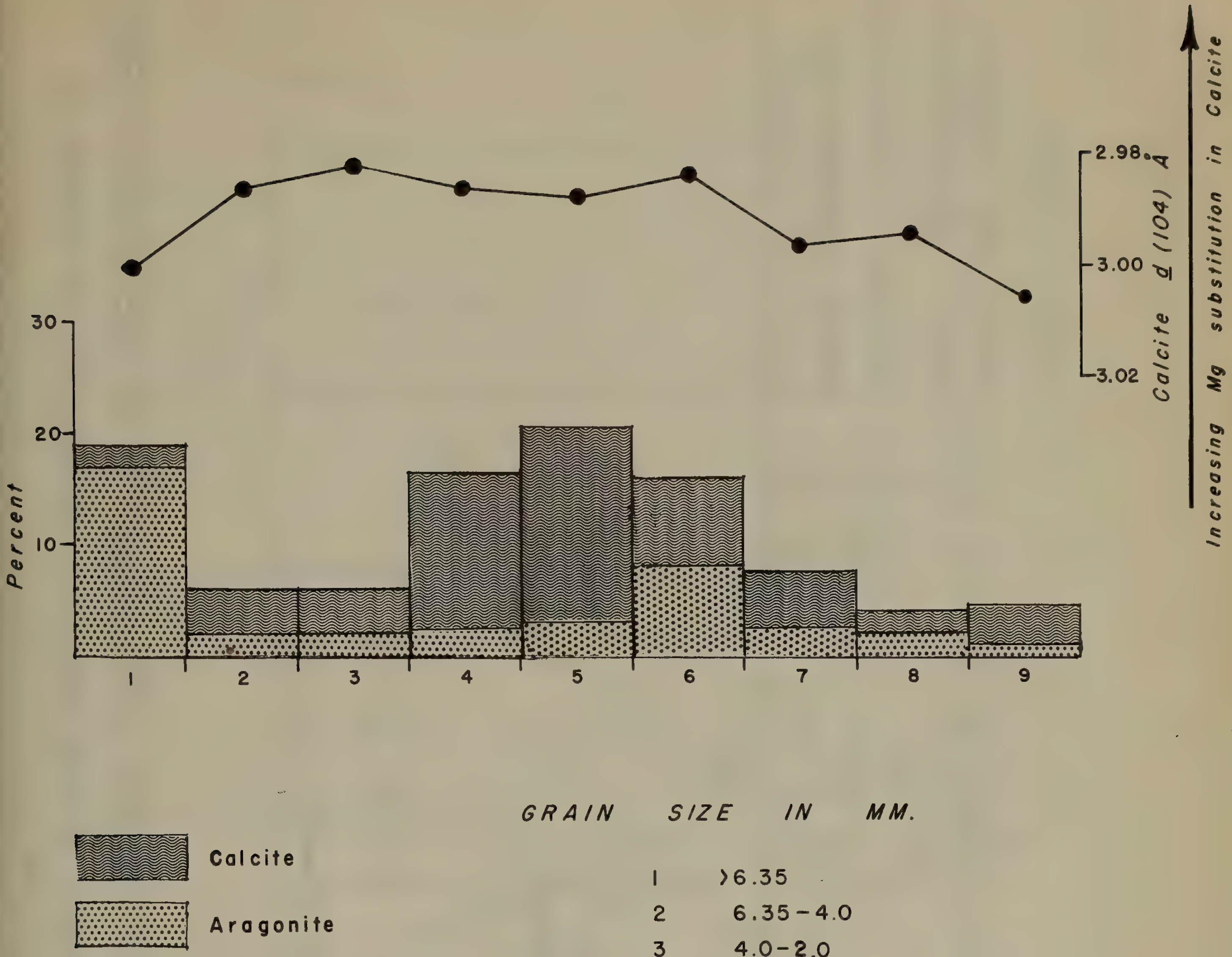


FIGURE 19. GRAIN SIZE DISTRIBUTION AND RELATIVE AMOUNTS OF CALCITE AND ARAGONITE IN SOILS ON UTIRIK, JEMO, LIKIEP, AND TAKA ATOLLS



1	>6.35
2	6.35 – 4.0
3	4.0 – 2.0
4	2.0 – 1.0
5	1.0 – 0.5
6	0.5 – 0.25
7	0.25 – 0.12
8	0.12 – 0.06
9	<0.06

FIGURE 20. AVERAGE MINERALOGIC COMPOSITION OF SOIL PROFILES EXAMINED FROM THE ARNO ATOLL AND SHIOYA SOIL SERIES AS SHOWN IN FIGURE 19

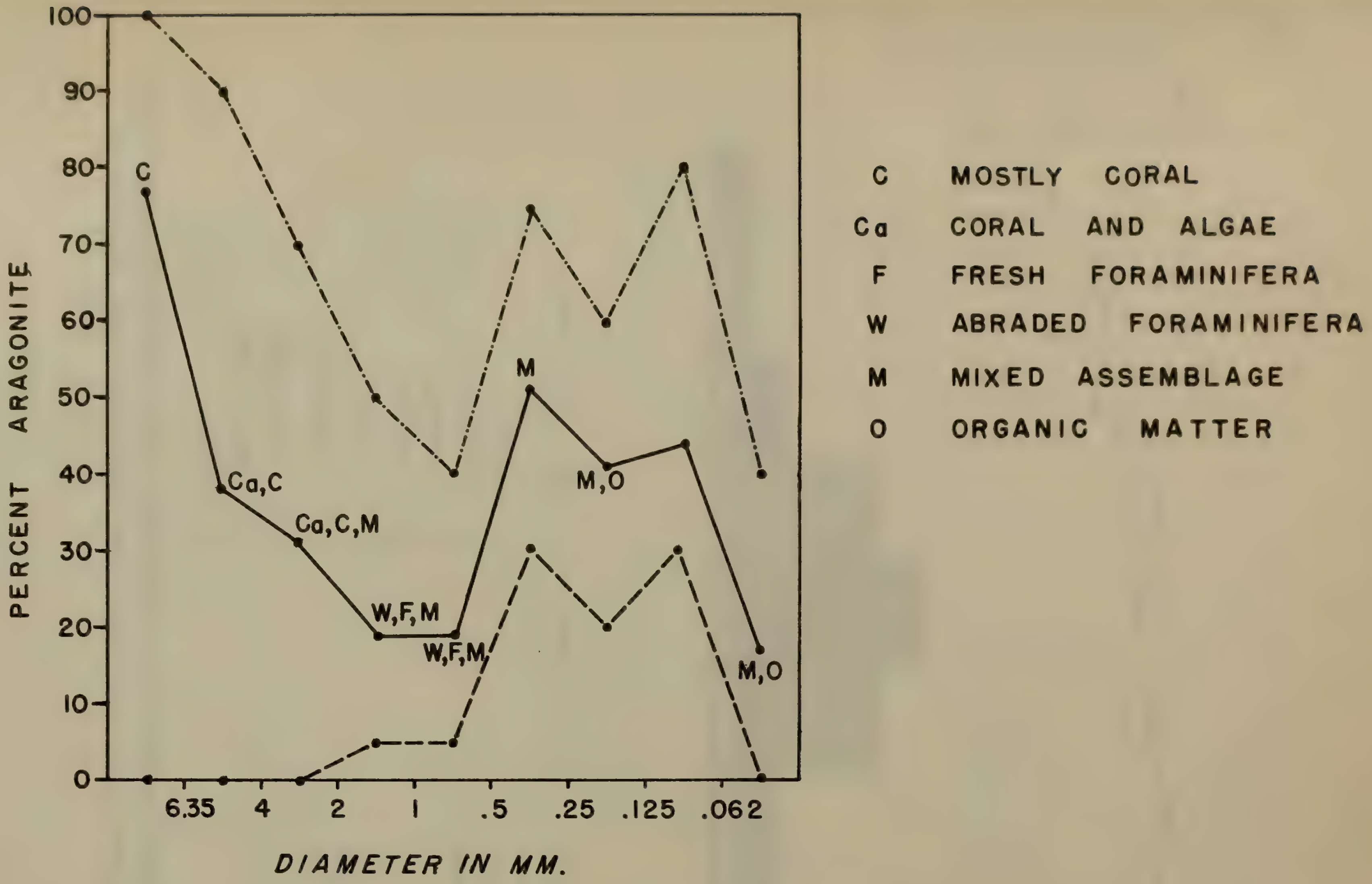


FIGURE 21. MAJOR CONSTITUENTS AND ARAGONITE IN THE VARIOUS GRAIN SIZES OF SOILS IN THE PROFILES DESCRIBED IN FIGURE 19

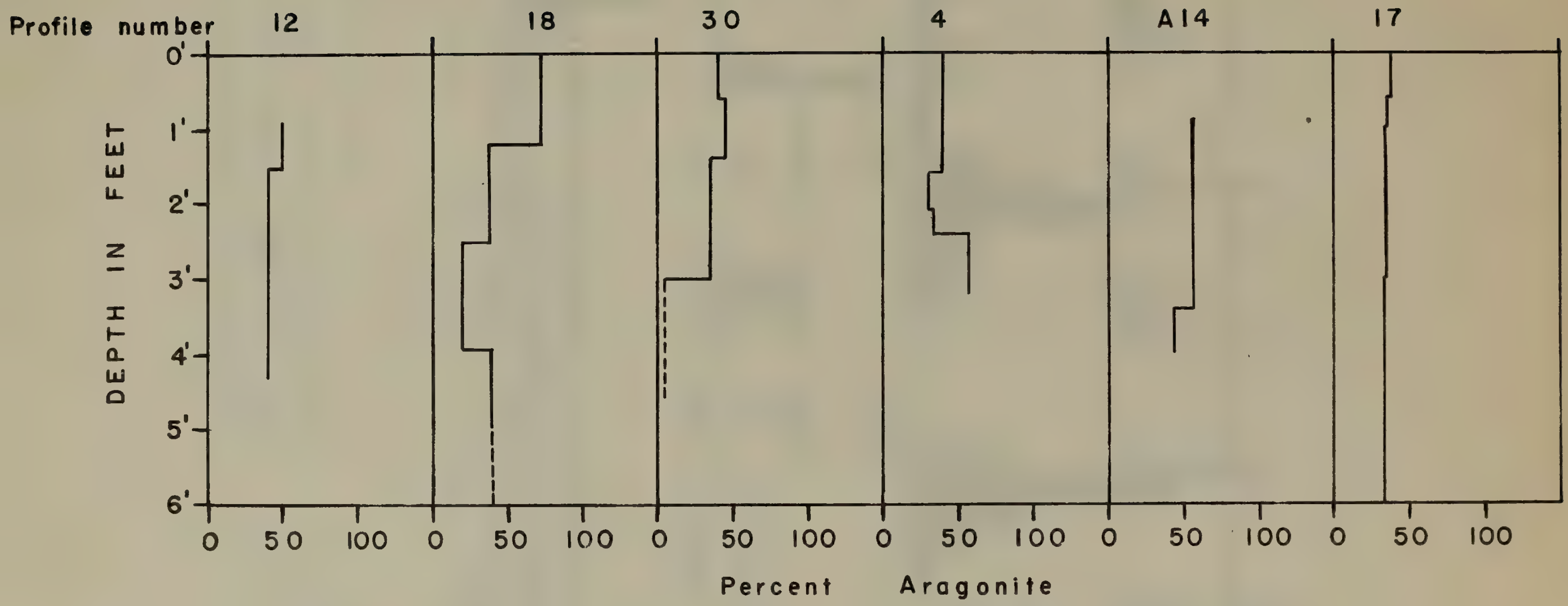
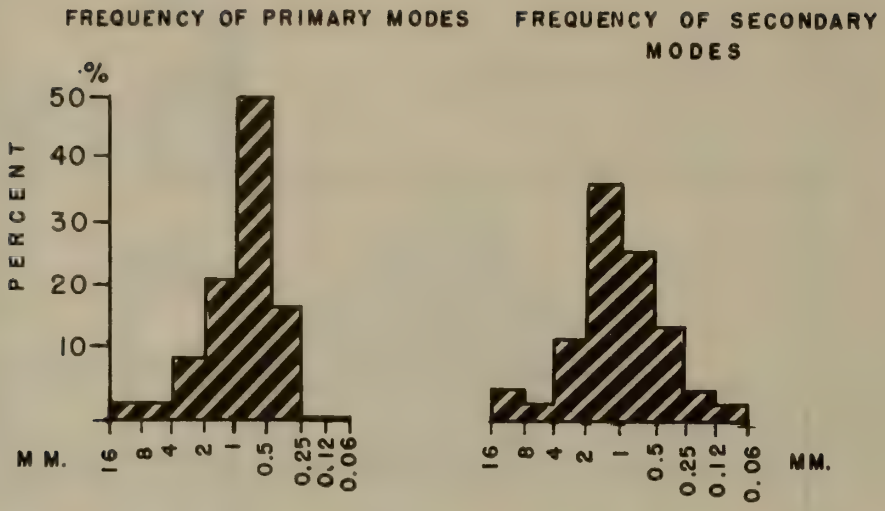
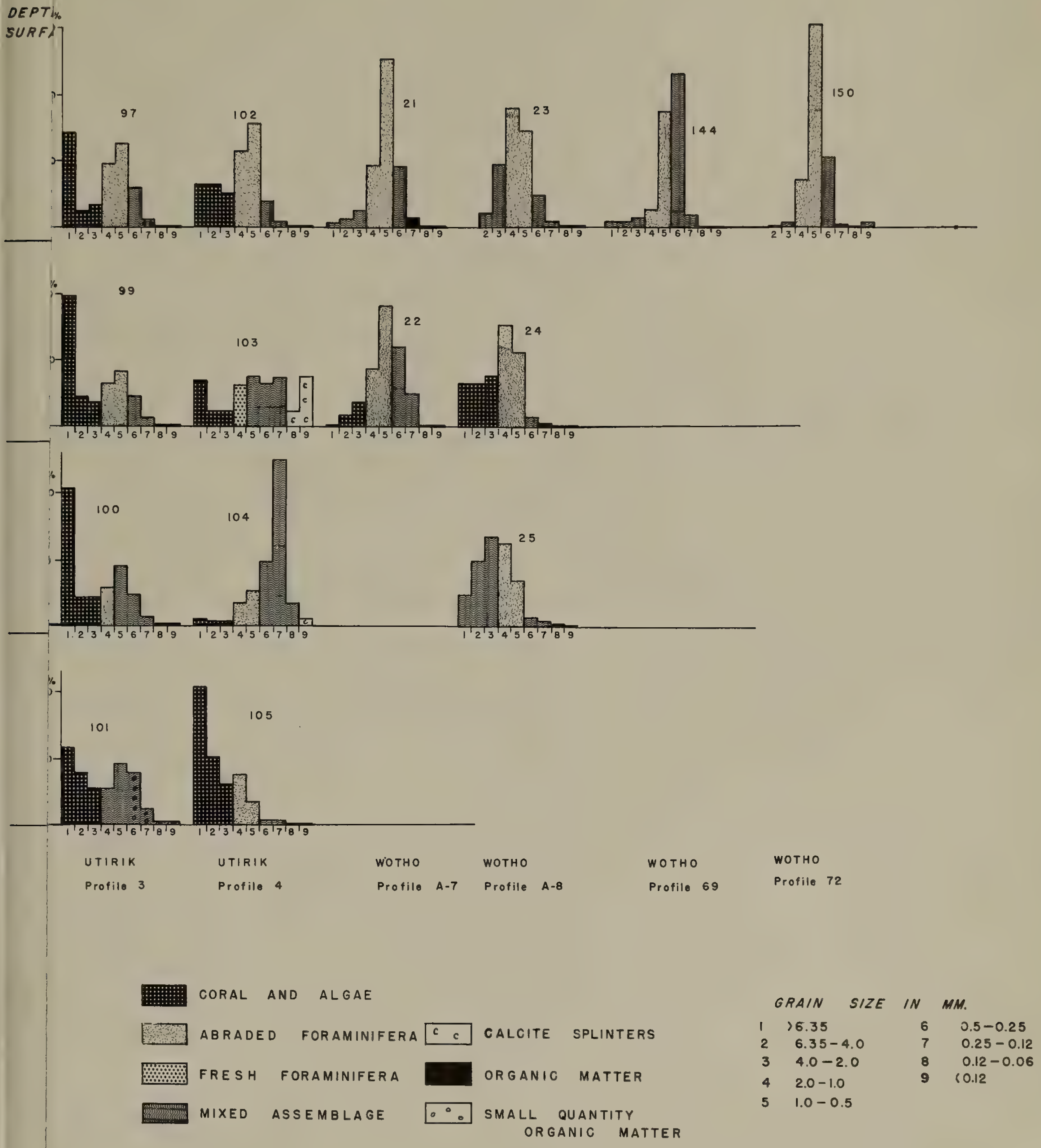


FIGURE 22. ARAGONITE CONTENT OF THE SOIL PROFILES SHOWN IN FIGURE 19



	MEDIAN MM	SORTING COEFF.	SKEWNESS
SEAWARD BEACHES	1·27	1.66	1.43
LAGOON BEACHES	0.86	1.54	1.07

FIGURE 23. FREQUENCY OF PRIMARY AND SECONDARY MODES IN THE SIZE DISTRIBUTION OF ALL BEACH SANDS EXAMINED FROM THE NORTHERN MARSHALL ISLANDS


DEPTH
SURF
%
97
102
21
23
144
150
99
103
22
24
100
104
25
101
105
1 2 3 4 5 6 7 8 9
c
UTIRIK
Profile 3
UTIRIK
Profile 4
WOTHO
Profile A-7
WOTHO
Profile A-8
WOTHO
Profile 69
WOTHO
Profile 72
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED ASSEMBLAGE
CALCITE SPLINTERS
ORGANIC MATTER
SMALL QUANTITY ORGANIC MATTER
GRAIN SIZE IN MM.
1 >6.35
2 6.35-4.0
3 4.0-2.0
4 2.0-1.0
5 1.0-0.5
6 0.5-0.25
7 0.25-0.12
8 0.12-0.06
9 <0.12

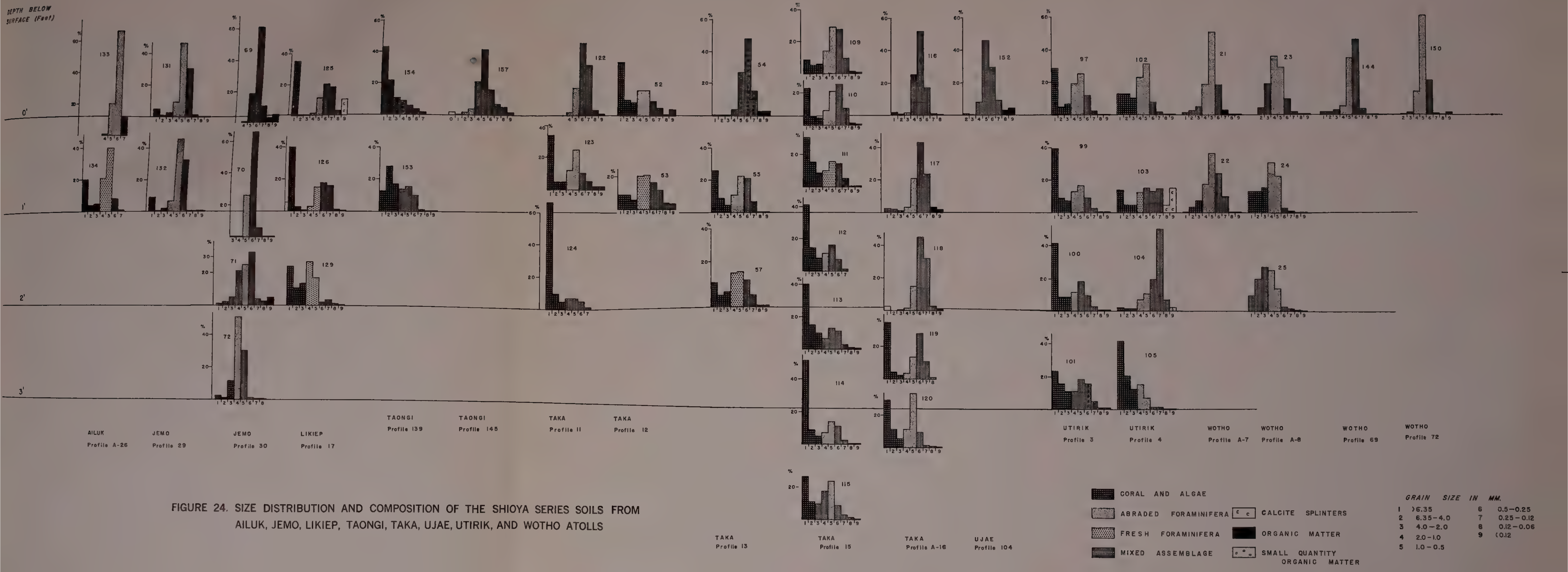


FIGURE 24. SIZE DISTRIBUTION AND COMPOSITION OF THE SHIOYA SERIES SOILS FROM AILUK, JEMO, LIKIEP, TAONGI, TAKA, UJAE, UTIRIK, AND WOTHO ATOLLS

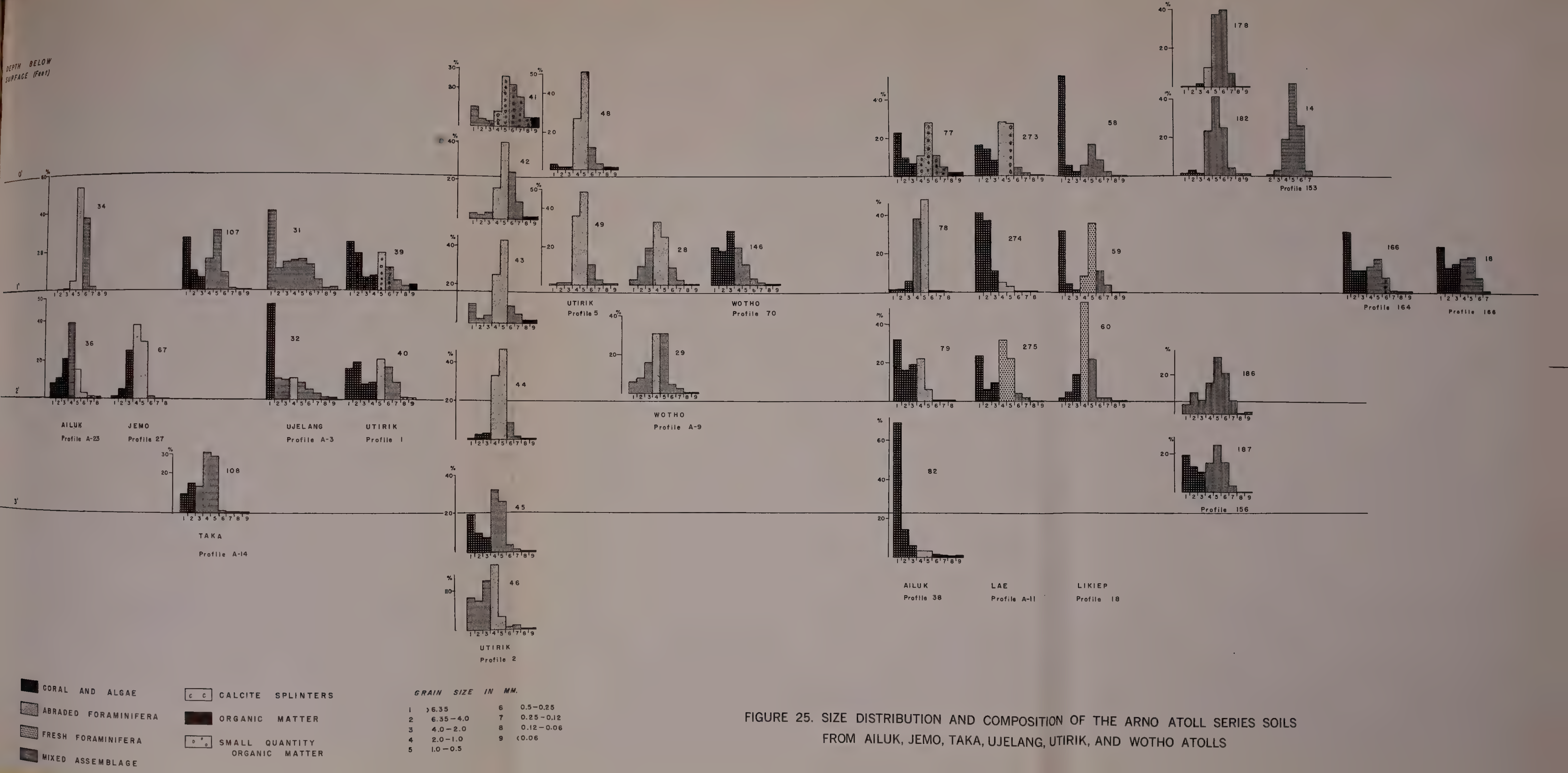


FIGURE 25. SIZE DISTRIBUTION AND COMPOSITION OF THE ARNO ATOLL SERIES SOILS FROM AILUK, JEMO, TAKA, UJELANG, UTIRIK, AND WOTHO ATOLLS

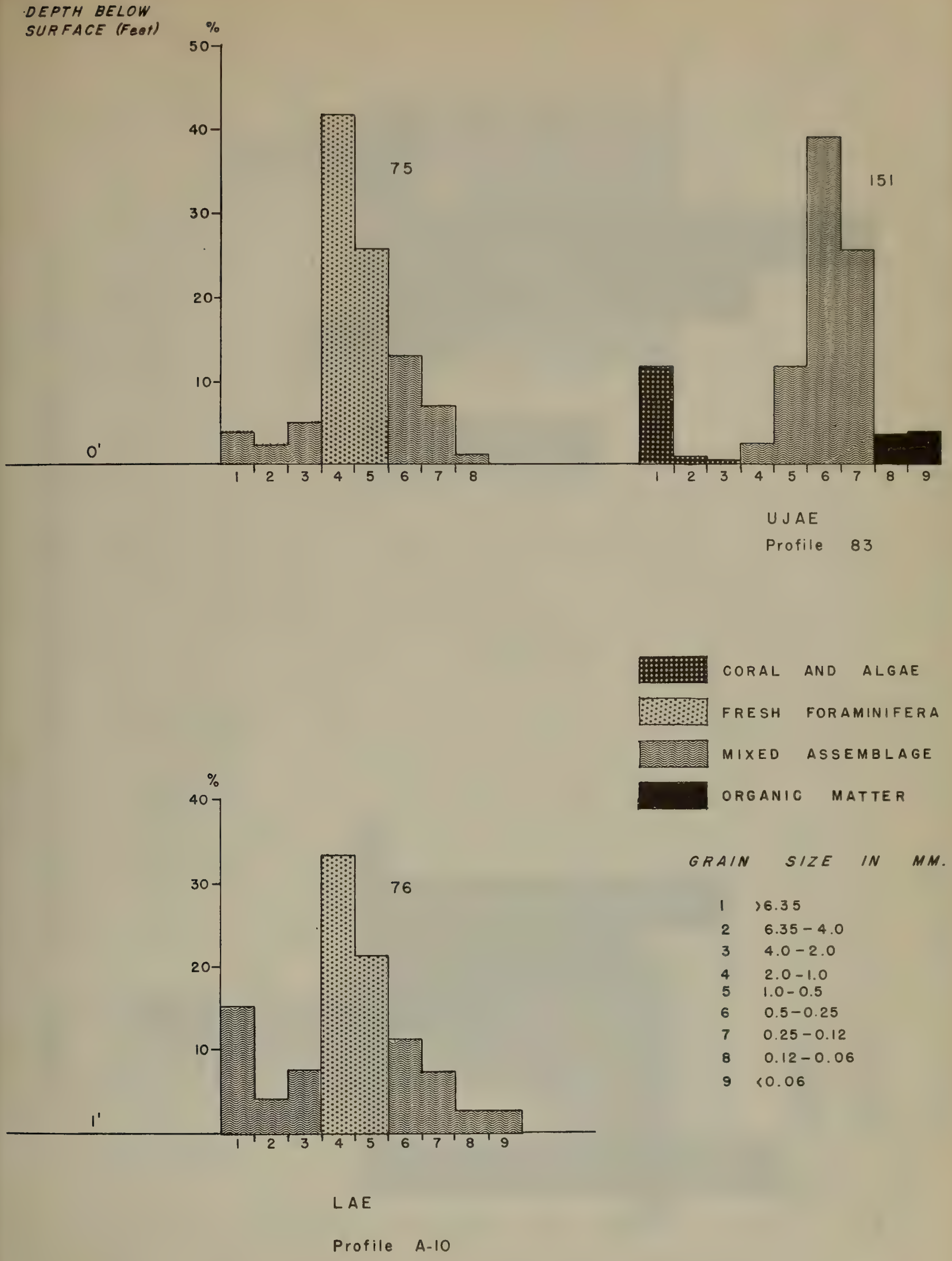


FIGURE 26. SIZE DISTRIBUTION AND COMPOSITION OF UNCLASSIFIED SOILS

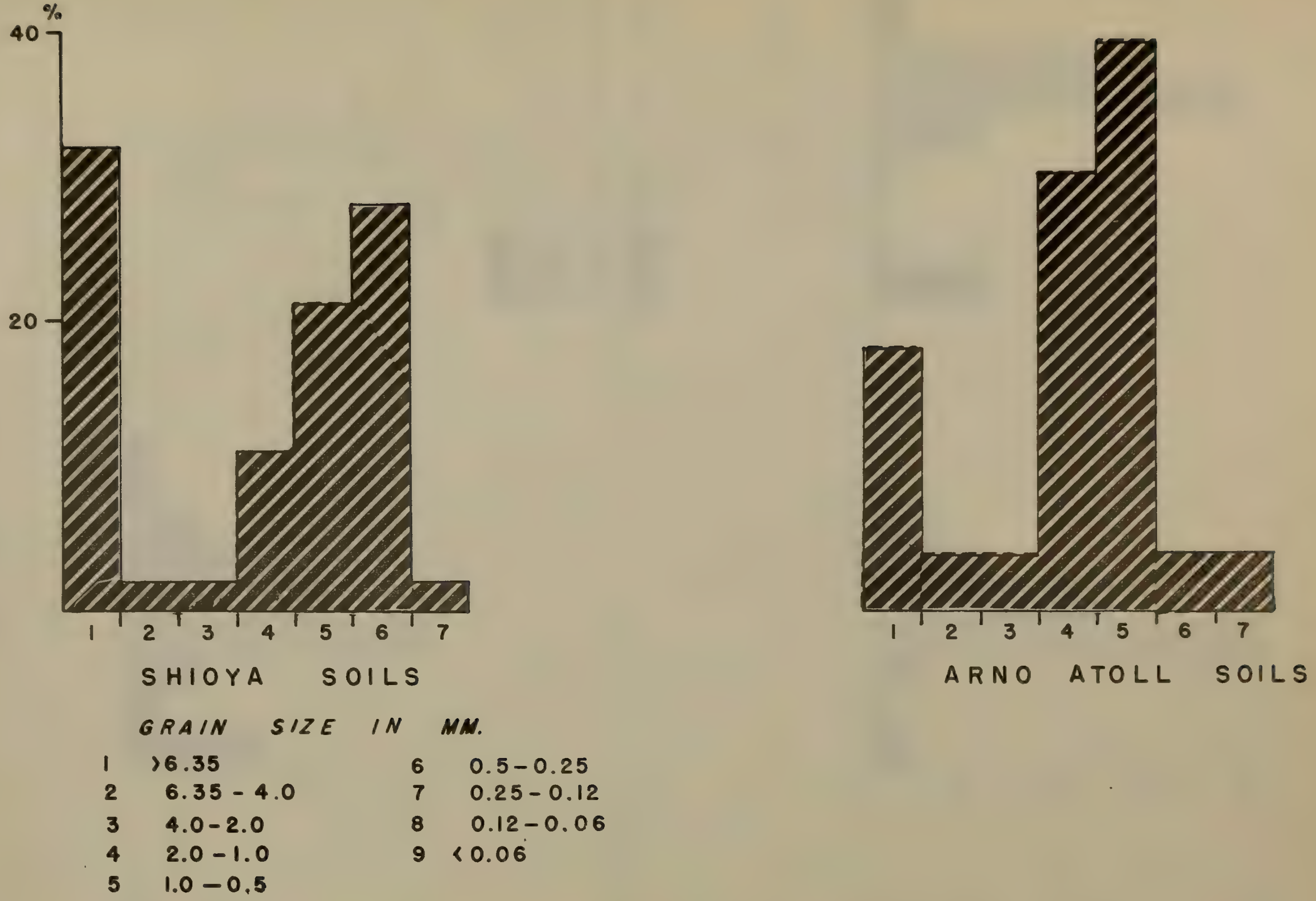


FIGURE 27. DISTRIBUTION OF THE MODES IN SHIOYA AND ARNO ATOLL SOILS

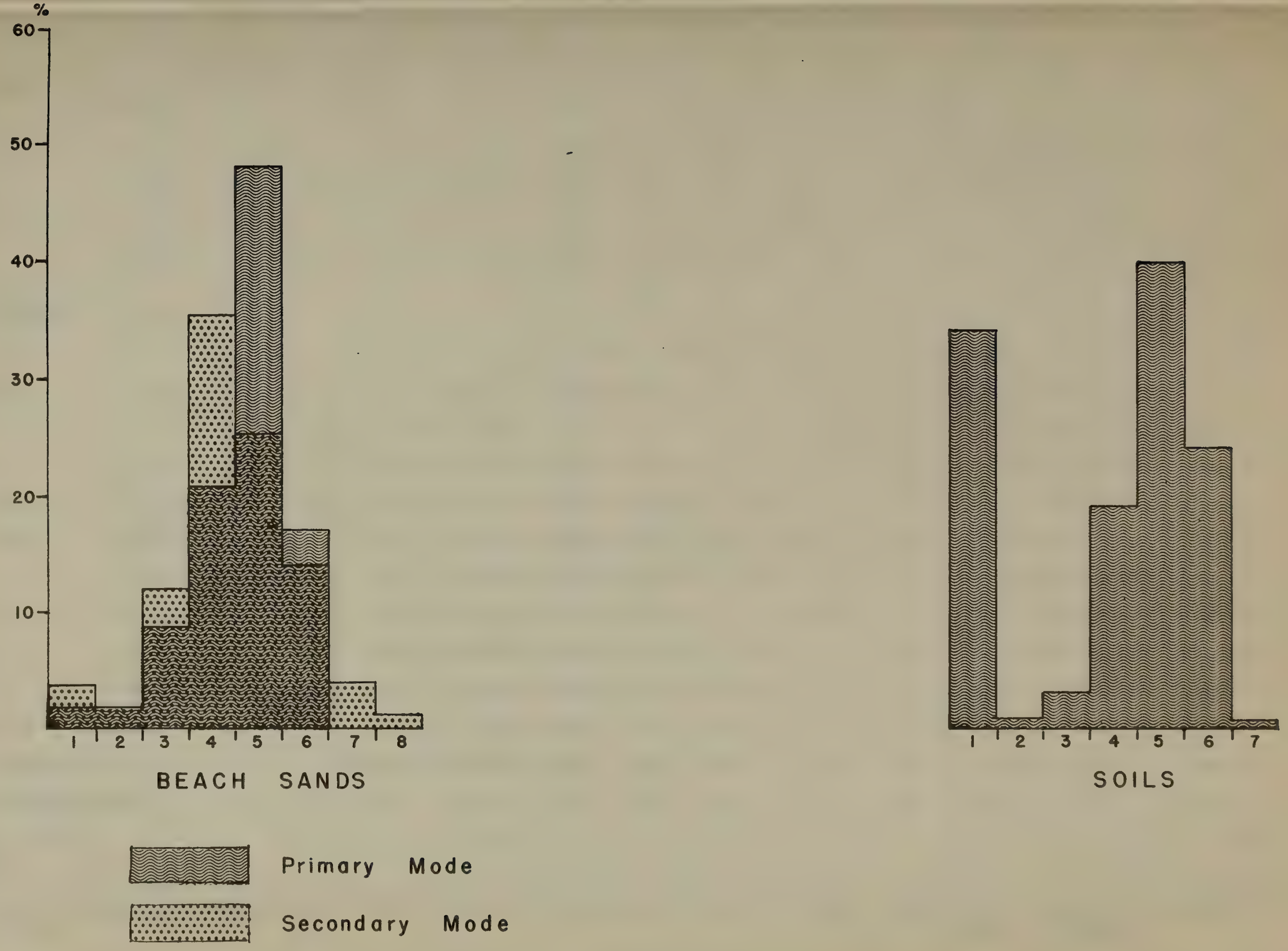


FIGURE 28. COMPARISON OF GRAIN SIZE DISTRIBUTION OF BEACH SANDS AND SOILS

Table 4.--Size distribution (percent by weight), median grain diameter, sorting coefficient, and skewness of beach sands from islets on various atolls in the northern Marshall Islands. (Situation of sample on islet is indicated by S, seaward, and L, lagoon).

Atoll and islet	Sample No.	Situation	Grain size (mm)									Median (mm)	Sorting coefficient	Skewness
			+8.0	+4.0	+2.0	+1.0	+0.50	+0.25	+0.125	+0.062	<0.062			
Taongi: (Pokak) Atoll														
North	T 16	S	1.4	1.7	9.5	18.7	28.0	26.4	12.5	1.0	0.3	0.60	1.90	1.08
	T 17	L	.3	2.8	23.6	28.7	34.5	9.6	tr	tr	tr	1.15	1.67	1.06
Kamwome	T 15	S	.4	.8	6.7	34.4	43.9	13.2	.1	tr	tr	.90	1.38	.92
	T 19	S	1.3	2.1	18.6	37.8	22.2	10.2	7.0	.2	.1	1.10	1.67	.93
	T 10	S	1.9	4.0	12.4	20.6	39.6	21.1	.1	tr	tr	.80	1.70	1.17
	T 14	L	1.5	3.9	12.8	36.8	42.8	1.1	.6	tr	.1	1.10	1.52	.99
	T 13	L	2.0	1.6	4.6	16.9	60.2	13.6	.1	.3	.3	.78	1.26	.98
	T 12	L	-	tr	1.0	9.2	24.3	32.5	26.4	3.3	3.0	.37	1.73	.87
	T 11	L	2.4	.7	1.5	5.1	48.9	40.6	.3	tr	tr	.52	1.41	1.01
Bwdije	T 8	S	1.3	11.7	31.2	30.3	23.5	1.5	tr	tr	tr	1.60	1.80	.98
	T 9	L	2.8	6.4	18.3	21.3	37.0	12.0	1.4	.1	.2	.99	1.73	1.28
Sibylla	T 7	S	-	.7	2.4	6.5	33.3	42.0	14.2	.4	.1	.45	1.52	1.04
	T 6	S	-	-	9.3	73.0	17.1	.3	tr	tr	tr	1.30	1.22	.99
	T 32	S	-	tr	.3	5.1	56.5	37.4	.3	tr	tr	.58	1.14	1.06
	T 5	S	2.9	2.5	5.9	19.0	32.8	31.4	5.1	tr	tr	.66	1.73	1.10
	T 21	S	-	1.4	16.9	50.5	18.9	6.2	5.5	.2	tr	1.20	1.48	1.00
	T 27	L	.6	.3	2.6	9.5	19.5	20.3	17.0	15.5	14.3	.28	2.65	.71
	T 4	L	2.8	4.8	13.4	39.5	26.3	1.0	1.4	9.0	1.3	1.20	1.58	.90
	T 20	L	.4	2.5	13.4	30.2	36.8	14.6	1.7	tr	tr	.92	1.58	1.02
	T 22	L	.2	.6	5.0	31.3	56.3	5.1	.4	tr	tr	.81	1.34	1.00

Pokak	T 26	S	-	.2	.2	.9	12.6	62.7	22.8	.4	tr	.32	1.41	1.02
	T 25	S	-	.4	.2	.7	3.7	56.7	38.0	tr	tr	.27	1.30	1.03
	T 23	L	3.3	6.9	24.2	31.5	25.7	7.7	.3	tr	tr	1.40	1.90	.90
	T 24	L	.3	1.4	20.4	50.4	25.8	1.3	tr	tr	tr	1.30	1.41	1.05
Bwokwla	T 29	S	2.1	4.0	9.5	27.4	45.5	10.5	.7	tr	tr	.90	1.48	1.07
	T 30	S	.2	tr	.7	10.5	79.6	8.6	tr	-	-	.90	1.45	1.14
Bikar Atoll Jabwelo	B 14	S	2.3	4.8	19.0	40.1	26.7	6.0	.4	.1	.3	1.20	1.61	1.16
	B 15	S	2.7	3.3	10.8	22.7	35.6	19.6	4.5	.3	.1	.80	1.73	1.17
Almani	B 13	L	2.6	4.9	21.1	28.1	22.3	15.0	5.2	.4	tr	1.10	2.02	.81
	B 11	L	13.5	13.2	29.4	21.4	10.5	8.6	3.1	tr	tr	2.20	1.92	.93
	B 12	S	9.7	9.5	14.9	19.8	35.3	8.9	1.5	tr	tr	2.20	1.92	.93
Jaboero	B 16	S	2.9	8.9	14.8	17.8	34.2	17.9	2.9	tr	tr	.80	1.95	1.62
Bikar	B 4	S	2.3	8.2	21.1	35.7	17.6	5.9	4.2	1.6	.5	1.40	1.84	.93
	B 5	S	.4	3.1	10.1	27.0	37.7	19.2	2.2	tr	tr	.84	1.98	.60
	B 6	S	.4	2.0	1.8	6.1	39.8	44.4	5.0	tr	tr	.50	1.30	1.03
	B 7	S	3.6	9.0	13.5	16.4	19.7	20.3	15.1	1.5	.4	.80	2.51	1.08
	B 3	L	-	.4	3.0	16.4	41.2	34.1	4.5	tr	tr	.60	1.64	.83
	B 8	L	.7	3.1	6.5	24.9	57.5	6.8	.1	tr	tr	.79	1.34	1.07
Ailuk Atoll	6	S	20.0	6.0	50.0	20.0	3.0	1.0	-	-	-	2.60	1.45	1.27
Kwajalein Atoll														
Torrutj	9	S	.5	.5	35.0	3.0	60.0	1.0	-	-	-	.92	1.70	2.03
	J 10	S	-	1.7	19.6	13.2	52.4	12.7	tr	tr	tr	.74	1.79	1.61
	10	L	-	-	tr	1.0	97.0	2.0	-	-	-	.80	1.10	.89
	J 1	L	-	.1	.2	1.7	85.4	11.9	.5	tr	tr	.64	1.09	.98

Atoll and islet	Sample No.	Situation	Grain size (mm)									Median (mm)	Sorting coefficient	Skewness
			+8.0	+4.0	+2.0	+1.0	+0.50	+0.25	+0.125	+0.062	<0.062			
Ninni	11	L	-	-	22.9	12.3	19.3	29.4	15.3	tr	-	.52	2.36	2.13
	J 2	L	.5	15.8	8.0	9.3	19.2	21.9	24.9	tr	tr	.54	2.76	1.63
Eniwetok	12	L	-	-	.7	1.5	17.4	67.4	12.5	tr	-	.36	1.26	.97
	J 7	L	-	tr	tr	.9	16.6	60.7	21.5	tr	tr	.35	1.26	.99
Lae Atoll														
Enejalto	14	S	15.0	10.0	30.0	35.0	10.0	tr	-	-	-	2.20	1.68	1.15
Enemanit	J 11	L	6.0	10.1	25.9	49.1	6.5	.9	.8	.2	.2			
Taka Atoll														
Taka	5	S	tr	.5	8.0	35.0	55.0	1.5	-	-	-	.96	1.18	1.06
	J 3	S	-	.3	9.7	46.6	33.5	7.3	2.2	tr	tr	1.00	1.26	.88
	28	S	40.0	30.0	20.0	5.0	5.0	tr	-	-	-	n.d.	n.d.	n.d.
	TW 4	L	9.0	3.9	5.7	29.2	29.2	8.6	9.2	3.2	1.5	.96	1.00	2.20
Likiep Atoll														
Emejiwan	J 8	S	-	1.3	10.9	52.6	35.0	.1	tr	tr	tr	1.05	1.26	1.06
	7	S	-	tr	25	23	50	2	-	-	-	1.0	1.55	1.64
Ujae Atoll														
Bokerok	13	L	tr	tr	1	5	84	10	-	-	-	.78	1.0	.83
	J 6	L	19.6	tr	1.2	9.0	43.8	25.8	.3	tr	tr	.68	1.70	1.45
Ujelang Atoll														
Ujelang	J 4	S	17.0	6.1	5.5	27.3	41.7	1.9	tr	tr	tr	1.10	1.87	2.08
	J 5	S	-	.8	24.3	34.2	34.2	5.2	.5	.1	.1	1.20	1.64	1.02
	J 9	S	13.2	11.0	26.8	31.3	13.7	2.8	.6	.1	tr	2.10	1.79	1.06

	23	L	50	4	12	8	20	6	-	-	-	n.d.	n.d.	n.d.
Nelle	24	L	tr	tr	2.5	2.5	40	55	-	-	-	.38	1.34	1.12
Maronlik	25	S	2.5	10	35	25	25	2.5	-	-	-	1.90	1.70	.73
	26	L	20	5	7	13	55	tr	-	-	-	.90	2.60	3.66
Utirik Atoll														
Utirik	2	L	-	-	9.2	7.5	10.5	52.5	19.4	.5	-	.35	1.41	1.14
	3	L	30	4	15	15	35	1	-	-	-	1.90	-	-
	1	L	-	1	6	15	75	3	-	-	-	.92	1.10	.90
	U 5	L	98.5	.6	tr	tr	tr	.5	.2	tr	tr	n.d.	n.d.	n.d.
Wotho Atoll														
Wotho	15	S	20	8	30	20	20	2	-	-	-	1.30	2.02	4.26
	16	S	tr	tr	2	13	70	15	-	-	-	.70	1.18	1.01
	17	L	-	-	2.5	2.0	35.0	59.4	.5	-	-	.44	1.26	.98
	18	S	tr	5	85	10	tr	-	-	-	-	2.50	1.10	1.03
Eirek	19	L	tr	-	tr	4	95	2	-	-	-	.78	1.05	.85
	21	L	tr	tr	5	40	45	10	-	-	-	.98	1.22	.82

Table 4.--Size distribution (percent by weight), median grain diameter, sorting coefficient, and skewness of beach sands from islets on various atolls in the northern Marshall Islands. (Situation of sample on islet is indicated by S, seaward, and L, lagoon).

Analysts, F. S. MacNeil, G. W. Chloe, Dorothy Carroll

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Atoll	Profile No.	Sample No.	Depth (feet)	Organic carbon (percent)	pH	>8.0	8.0-4.0	4.0-2.0	2.0-1.0	1.0-.5	.5-.25	.25-.12	.12-.06	<0.06	Median	Sorting coefficient	Skewness
Shioya soil series																	
Wotho	71	147	0-0.3	3.52	8.0	...	...	...	...	...	...	...	...	...	...	...	...
Wotho	72	148	0-0.3	2.53	8.0	...	...	...	...	...	...	...	...	...	...	...	...
		149	0.3-0.5	1.24	8.6	...	...	...	...	...	...	...	...	...	...	...	...
		150	0.5-1.8	...	...	...	.1	1.8	14.1	60.6	21.0	.6	.1	1.6	.66	1.30	.98
Ailuk	A26	133	0-1.0	...	...	...	...	.2	1.1	20.0	66.0	12.0	.6	.2	.37	1.22	.97
		134	1.0-4.0	...	...	20.5	4.0	5.5	21.0	39.9	8.0	.8	.2	.2	1.05	2.26	2.16
Taongi (Pokak)	141	156	0-0.08	1.05	8.8	...	...	...	...	...	...	...	...	...	...	...	...
Taongi (Pokak)	145	157	0-0.85	...	...	1.7	.6	2.4	4.1	21.1	41.3	15.8	7.3	5.6	.36	1.58	.95
Taongi (Pokak)	139	154	0-0.13	...	...	43.5	22.0	11.5	9.4	6.3	4.3	2.2	.6	.2	6.9	...	...
		153	0.13-1.1	...	...	13.4	28.0	17.1	13.9	15.7	10.1	1.6	.2	.2	2.8	2.6	.70
Likiep	17	125	0-0.6	...	...	35.0	.3	.4	1.7	11.0	19.6	18.3	3.4	10.3	.47	...	...
		126 127	0.6-3.0	...	...	40.8	3.3	1.3	3.4	15.2	17.7	16.9	1.3	.2	.90	...	...
		129 130	3.0-6.0	...	...	24.6	10.9	13.7	26.8	16.9	1.9	3.5	1.6	.3	1.9	...	...
Lae	46	138	0-0.3 or 0.9	...	...	12.4	3.7	3.2	4.6	18.4	32.6	17.6	3.1	4.4	.86	1.9	1.21
		139	0.3 or 0.9-6.0+	... ...	... ...	16.2	6.0	5.5	19.5	26.6	16.8	7.6	1.3	.7	.92	2.42	1.54

Jemo	29	131	0-0.5	...	...	5.5	1.1	2.5	9.2	47.2	31.6	1.3	.7	.8	.56	1.34	1.26
		132	0.5-2+	...	...	9.0	.8	2.2	7.4	46.4	33.6	.5	.1	.1	.60	1.34	1.09
Jemo	30	69	0-0.6	...	...	.4	...	.1	1.2	19.3	61.5	10.8	2.7	4.1	...	...	...
		70	0.6-1.4	...	...	.2	...	.1	.4	26.7	66.7	5.8	.2	.2	...	...	...
		71	1.4-3.0	...	...	1.7	1.8	5.5	21.6	25.0	32.5	4.6	2.3	4.7	...	...	...
		72} 73}	3.0-?	...	...	2.5	1.1	11.9	53.7	29.3	1.5	.3	.2	.1	...	...	...
Utirik	3	97	0-1.3	...	...	28.8	5.1	7.0	19.5	25.2	12.0	2.5	.1	.1	1.3	...	...
		98	1.3-1.9	1.37	8.3	Coral fragments and organic matter											
		99	1.9-2.3	...	...	39.6	9.4	7.5	12.9	17.1	9.7	3.3	.4	.2	3.7	...	...
		100	2.3-3.0	...	...	40.9	8.6	8.5	11.6	18.0	9.4	2.4	.3	.3	3.7	...	...
		101	3.0-4.2	...	...	23.1	15.3	10.9	11.0	18.1	15.8	4.5	.7	.5	1.9	...	...
Utirik	4	102	0-1.6	...	...	13.0	12.7	10.3	22.9	31.0	7.9	1.8	.3	.3	1.2	2.5	2.2
		103	1.6-2.2	...	...	14.0	5.2	5.0	12.6	15.2	12.6	15.5	4.6	15.5	.54	...	...
		104	2.2-2.5	...	...	2.0	1.3	1.5	6.9	10.8	19.6	50.0	6.3	1.8	.22	1.73	.14
		105	2.5-3.2	...	...	41.8	20.3	12.1	15.3	7.2	1.4	1.5	.3	.2	6.6	...	...
Ujae	104	152	0-1.0	...	...	...	.9	.3	7.5	46.0	29.5	9.0	2.7	4.1	.52	1.41	.80
Ujae	103	121	0-1.0	5.23	8.14	25 percent over 2 mm											
Ujae	101	89	0-0.5	7.4	7.7	38 percent over 2 mm											
Ujae	100	88	0-0.5	6.7	7.6	30 percent over 2 mm											
Wotho	A8	23	0-1.4	...	...	.3	4.4	18.5	36.0	29.1	9.8	1.7	.2	.2	1.2	1.61	.95
		24	1.4-1.9	...	...	13.3	13.5	15.8	30.7	22.7	2.9	.9	.3	.2	1.6	2.12	1.6
		25	1.9- ?	...	...	9.5	19.7	27.1	24.9	13.8	2.4	1.9	.5	.2	2.2	2.0	1.2

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Wotho	A7	21	0-1.6	...	...	1.7	2.4	5.0	18.7	50.5	18.0	3.2	.4	.3	.72	1.41	1.14
		22	1.6- ?	...	...	.5	3.7	7.7	17.7	36.4	23.9	10.0	.2	.2	.70	1.73	.95
Wotho	69	141 142 143	0-1.0	...	...					40 percent over 2 mm							
				...	...					6 percent over 2 mm, earthy							
		144	1.0-3.0	...	...	2.1	2.1	3.0	5.8	35.2	46.5	4.4	.5	.4	.48	1.08	1.26
Taka	A15	109	0-0.3	...	...	8.2	5.2	6.0	13.9	29.1	27.0	9.0	1.1	.5	.66	1.95	1.15
		110	0-3-0.9	...	...	22.8	5.7	4.5	9.0	20.8	25.6	10.3	.8	.6	.74	4.35	4.73
		111	0.9-1.4	...	...	30.4	15.3	8.3	9.8	15.7	14.2	5.4	.5	.3	2.7	...	...
		112	1.4-1.8	...	...	41.2	14.2	8.2	11.2	16.1	7.7	1.2	.1	.1	5.4	...	...
		113	1.8-2.1	...	...	40.1	15.0	9.4	6.7	13.1	11.6	2.9	.7	.6	4.8	...	...
		114	2.1-3.1	...	...	50.5	8.9	5.0	7.4	14.2	11.1	2.4	.3	.2	...	...	...
		115	3.1-8.8	...	...	26.1	10.9	9.4	17.6	23.8	8.7	2.6	.8	.4	1.7	3.68	2.35
Taka	11	122	0-0.8	...	...	...	tr	tr	2.1	17.0	45.2	31.6	3.4	.6	.86	1.41	1.81
		123	0.8-1.5	...	...	34.1	4.8	5.0	12.0	24.4	10.4	5.0	2.0	2.4	...	...	...
		124	1.5-3.0	...	...	66.0	9.4	4.3	6.7	6.9	5.1	1.2	.2	.2	...	...	...
Taka	A16	116	0-0.5	...	...	...	1.7	.3	1.8	25.1	52.4	17.3	1.1	.3	.39	1.34	1.03
		117	0.5-1.2	...	...	2.5	2.0	1.2	3.2	20.4	43.0	23.2	2.8	1.7	.35	1.55	1.36
		118	1.2-1.9	...	...	2.5	tr	.27	1.7	14.7	45.0	32.3	3.0	.5	.27	1.38	1.26
		119	1.9-2.8	...	...	35.0	4.5	2.5	4.0	13.6	28.2	11.1	.8	.4	.80	...	...
		120	2.8-5.7	...	...	28.6	10.9	5.5	10.8	33.0	9.1	1.6	.4	.1	1.4	...	...

Taka	13	54	0-0.25	...	...	.5	.3	.5	3.8	26.5	47.4	15.3	3.0	2.8	.36	1.41	1.16
		55	0.25-2.0	...	...	25.9	8.8	4.5	10.3	22.0	20.2	7.3	.4	.6	.94	4.55	4.58
		56	2.0-2.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		57	2.5-4.4	...	...	14.9	7.5	9.4	20.9	21.4	16.3	7.6	.9	1.1	1.05	2.53	1.35
								Arno Atoll soil series									
Utirik	1	37	0-0.7	6.01	8.0			60 percent over 2 mm									
		38	0.7-1.1	3.2	8.1			57 percent over 2 mm									
		39	1.1-2.7	1.8	...	24.6	18.7	6.6	7.7	19.5	12.0	5.5	2.3	3.0	2.0	4.07	1.21
		40	2.7-4.0	...	...	16.1	19.3	8.1	8.8	20.3	16.7	8.5	1.2	.8	1.2	3.64	1.87
Utirik	2	41	0-0.2	...	8.3	10.2	3.8	2.9	7.9	26.5	22.1	16.1	5.3	5.3	.52	2.08	.85
		42	0.2-0.7	...	8.9	2.6	2.0	2.9	16.0	40.6	24.8	9.1	1.0	1.1	.68	1.58	.76
		43	0.7-1.8	...	8.8	9.8	2.2	3.9	25.3	43.4	8.8	4.5	1.1	.9	.86	1.53	1.13
		44			9.3	.7	2.9	3.8	33.6	46.7	9.3	2.3	.5	.5	.84	1.38	1.05
		45	1.8-7.0	...	...	19.2	9.9	7.4	32.1	25.9	3.2	1.3	.6	.6	1.35	2.55	2.64
		46	7.0-8 +	...	...	16.6	14.7	25.1	33.0	6.3	1.8	2.1	.4	.3	2.2	1.67	2.64
Utirik	5	47	0-0.7	3.49	7.9	...	...	...	...	...	...	...	...	...	...	...	...
		48	0.7-1.5	...	...	2.9	1.2	1.2	26.8	51.0	11.7	3.4	.9	.7	.68	1.38	1.33
		49	1.5-2.5	...	...	.3	.8	1.0	36.0	48.2	10.7	2.4	.4	.3	.86	1.31	.95
		50	2.5- ?	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ujelang	A3	30	0-1.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		31	1.5-2.4	...	...	20.5	11.0	14.5	15.9	16.2	13.5	5.5	1.3	1.8	1.65	...	...
		32	2.4- ?	...	...	48.7	10.5	10.0	10.9	9.0	5.8	3.2	.9	1.1	...	...	...
Taka	A14	106	0-0.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		107	0.9-3.4	...	...	26.6	9.9	6.6	15.9	30.6	8.9	.9	.2	.5	1.4	3.8	3.3

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

		108	3.4-4.0	...	...	9.7	15.2	13.8	30.8	28.6	1.2	.4	.3	.1	1.35	2.1	1.9
Wotho	70	145	0-1.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		146	1.0-1.7	...	...	19.2	17.8	28.0	19.1	10.2	3.7	1.2	.4	.5	2.7	2.16	1.26
Wotho	A9	27	0-1.0	3.47	7.8	...	...	...	...	...	...	...	...	...	...	...	...
		28	1.0-2.0	...	...	2.4	9.5	19.0	32.4	24.8	8.9	2.4	.4	.3	1.35	1.73	.96
		29	2.0-5.0	...	...	6.0	8.1	16.1	31.3	31.2	4.4	2.7	.2	.2	1.2	1.76	1.20
Ujae	84	86	0-0.5	4.9	7.5	...	...	...	...	...	...	...	...	...	...	...	...
Ujae	98	87	[1]/Surface	7.6	7.3	...	...	...	...	...	...	...	...	...	...	...	...
Jemo	27	63	0-0.7	11.0	7.3	...	...	...	...	...	...	...	...	...	...	...	...
		64	0.7-1.1	5.0	7.5	...	...	...	...	...	...	...	...	...	...	...	...
		65	0.7-1.1	1.5	7.8	...	...	...	...	...	...	...	...	...	...	...	...
		66	1.1-2.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		67,68	2.4- ?	...	...	1.1	4.7	25.0	38.4	29.7	1.0	.3	.1	.1	1.3	1.64	1.04
Ailuk	A23	33	0-1.2	2.75	8.1				40 percent over 2 mm								
		34	1.2-1.7	...	...	.3	1.0	5.4	53.5	37.1	2.1	.3	.2	.2	.56	1.34	0.87
		35	1.7-2.4	2.1	8.3				63 percent over 2 mm								
		36	2.4-4.3	...	...	7.9	11.3	20.9	39.4	14.8	2.5	1.7	.7	.6	1.7	1.67	1.18
Ailuk	38	77	0.1.0	3.75	8.0	22.9	10.0	7.1	11.5	28.5	11.0	4.8	2.2	2.2	1.1	3.04	2.58

		78	1.0-1.8	...	...	2.1	1.9	6.0	38.4	47.7	1.2	1.2	.9	.6	.98	1.34	1.08
		79 80	1.8-2.7	...	...	32.0	16.1	18.9	22.2	6.6	1.4	1.3	.9	.7	3.7	...	...
		81	2.7-3.0	1.08	8.5	...	...	...	...	...	...	...	...	...	...	...	...
		82	3.0-3.74	...	...	69.6	14.2	6.1	3.6	3.2	1.6	.5	.4	.6	...	...	...
Likiep	18	58	0-1.3	...	...	52.5	6.1	2.7	6.5	17.2	8.9	3.1	1.4	1.6	...	...	...
		59	1.3-2.5	...	...	32.1	5.0	2.0	8.5	36.2	11.3	3.8	.6	.5	.94	4.0	5.70
		60 61	2.5-3.9+	...	...	2.0	5.0	14.0	51.2	21.8	2.1	2.4	.6	.7	1.2	1.41	1.12
Lae	A11	272	0-0.6	4.79	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		273	0.6-1.4	...	...	16.2	14.3	8.5	27.8	26.8	3.7	1.3	.5	.8	2.0	1.48	.74
		[2]...	1.4-2.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		274	2.2-2.5	...	...	41.4	37.6	11.3	5.5	2.6	.8	.4	.2	.2	7.0	...	...
		275	2.5-5.0	...	...	23.6	5.8	9.3	31.5	22.3	4.4	1.8	.5	.7	1.4	2.51	2.51
								Jemo soil series									
Jemo	26	4	[3]1-0	33	3.8					Peaty, 3.7 percent coral fragments							
Jemo	25	1	[3]0.5-0	17.68	5.2					Peaty, 9.6 percent coral fragments							
		2	0-0.3	...	...												
		3	0.3-1.5	2.12	...					Peaty, 61.3 percent coral fragments							
Bikar	156	176	[3]0.15-0														
		177	0.0.1														
		178 179	0.1-0.6	...	...	.9	.5	1.8	10.5	37.6	40.5	7.2	.5	.5	.5	1.45	1.0
		182	1.2-2.5	...	...	1.2	2.7	1.4	23.3	41.0	24.7	4.4	.7	.8	.66	1.51	1.08
		186	4.8-8.8	...	...	5.5	10.9	7.8	16.1	29.3	21.6	7.1	.6	1.4	.76	4.2	2.02
		187	4.8-8.8	...	...	18.6	13.5	10.5	14.7	24.2	15.0	3.0	.2	.2	1.3	8.3	2.9

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Bikar	153	12	[3]0.1 to 0.15-0	31.4	4.5	...	...	...	...	...	...	...	...	...	...	...	...
		13	0-1.0	...	7.9	...	...	...	...	...	...	...	...	...	...	...	...
		14	1.0-1.2+	...	8.6	...	.6	2.7	19.3	47.7	26.6	2.8	.2	.2	.6	1.41	1.32
Bikar	166	15	[3]0.4-0	30.9	4.8	...	...	...	...	...	...	...	...	...	...	...	...
		16	0-0.6	...	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		17	0-0.6	...	7.6	...	...	...	...	...	...	...	...	...	...	...	...
		18	0.6-1.0+	...	8.5	24.0	13.5	14.9	18.2	19.3	8.2	1.7	.2	.2	.9	3.4	.59
Bikar	165	19	[3]0.7-0	30.9	5.3	...	...	...	...	...	...	...	...	...	...	...	...
		20	0-0.5	...	8.0	...	...	...	...	...	...	...	...	...	...	...	...
Bikar	164	166	0.25-0.6+	...	...	34.6	12.0	11.8	14.4	17.8	7.7	1.4	.2	.2	3.2	...	...
Miscellaneous soils																	
Lae	A7	266	0-0.5	19.8	7.3	...	...	...	...	...	...	...	...	...	...	...	...
		267	0.5-0.8	...	...	40.0	21.8	9.3	10.9	10.4	4.3	1.7	.8	1.1	1.6	2.09	2.24
		[8]268	0.8-2.5	...	...	52.6	26.3	12.8	4.1	1.5	.8	.8	.5	.6	...	...	...
Lae	A10	74	0-0.5	2.6	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		75	0.5-2.2	...	...	4.1	2.8	4.9	41.0	25.8	13.0	7.2	1.2	.7	2.0	1.41	.75
		76	2.2-3.8	...	...	13.0	3.9	6.8	32.9	20.9	11.0	7.0	2.3	2.3	1.15	1.79	.83
Lae	A8	269	0-0.5	8.17	7.5					12.5 percent over 2 mm							
		270	0.5-0.9	4.33	7.8					58.3 percent over 2 mm							

		271	0.9-1.5	...	...	5.6	5.2	9.5	22.4	44.4	8.1	2.6	.9	1.1	.88	1.61	1.24
Ujae	83	151	0-1.5	...	...	11.8	.9	.5	2.6	11.7	39.3	25.8	3.5	4.0	.32	1.67	1.09
Ujae	81	84	[3] 0.2 or 0.4-0	8.1	7.4					42 percent over 2 mm							
Ujae	102	90	0-1.0	9.4	7.7					31 percent over 2 mm							
Utirik	6	256	0-1.9	2.65	8.7					38 percent over 2 mm							
		257	1.9-2.5	1.45	9.0					30 percent over 2 mm							
		258	2.5-3.2+	...	...	25.0	9.9	8.3	9.4	13.1	8.6	8.1	5.8	11.9	1.2	6.25	1.44
Ujae	82	85	0-0.5	8.11	7.6					23 percent over 2 mm							
Taongi (Pokak)	138	[2] ...	0-0.1														
		[2] ...	0.1-0.3														
		155	0.3-0.8	...	...	21.4	7.0	6.4	8.9	18.6	22.6	8.8	3.1	3.3	.76	3.98	3.18
Ailuk	A21	263	0-0.9	11.67	7.7					45 percent over 2 mm							
		264	0.9-2.5	3.37	8.4					13.6 percent over 2 mm							
		265	2.5-3.0	...	...	24.6	12.3	9.6	9.7	23.7	10.8	5.6	1.7	2.1	1.5	3.31	1.65

[1] Thickness of layer not recorded.

[2] No sample.

[3] Depth of leaf litter or raw humus above the soil.

Atoll	Sample No.	Situation on atoll or islet	Sorting	Major constituents					Sorting caused by			Skewness		
				Corals, algae	Fresh Foraminifera	Worn Foraminifera	Mixed assemblage	None dominant	Organisms (Category A)	Agencies (Category B)	Both together (Category C)	Skewness (Sk)	Mean[1] (mm)	Sign of skewness
Taongi (Pokak)	T16	[2]S	1.90	...	...	...	...	+	...	+	...	1.08	0.88	+
Do	T15	S	1.38	...	...	...	+	...	...	...	+	.92	.97	+
Do	T19	S	1.67	...	+	...	...	...	+	...	...	.93	1.24	+
Do	T10	S	1.70	...	...	...	+	...	...	...	+	1.19	1.14	+
Do	T8	S	1.80	...	...	...	+	...	...	...	+	.98	2.08	+
Do	T7	S	1.52	...	...	...	+	...	...	...	+	1.04	.50	0
Do	T6	S	1.22	...	+	...	...	...	+	...	...	.99	1.30	0
Do	T32	S	1.14	+	...	...	...	...	+	...	...	1.06	.56	0
Do	T5	S	1.73	...	...	...	+	...	...	...	+	1.10	.86	+
Do	T21	S	1.48	+	...	...	...	...	+	...	...	1.00	1.36	+
Do	T26	S	1.41	...	...	...	+	...	...	...	+	1.02	1.01	+
Do	T25	S	1.30	...	...	...	+	...	...	...	+	1.03	.28	0
Do	T29	S	1.48	...	...	...	+	...	...	...	+	1.07	1.11	+
Do	T30	S	1.45	...	...	...	+	...	...	...	+	1.14	.77	-
Do	T17	[3]L	1.67	...	...	...	+	...	...	...	+	1.06	1.35	+
Do	T14	L	1.52	...	...	...	...	+	...	+	...	.99	1.79	+
Do	T13	L	1.26	...	...	...	+	...	...	...	+	.98	.93	+
Do	T12	L	1.73	...	...	...	+	...	...	...	+	.87	.44	+
Do	T11	L	1.41	...	...	...	+	...	...	...	+	1.01	.57	0
Do	T9	L	1.73	...	...	...	+	...	...	...	+	1.28	1.47	+
Do	T27	L	2.65	...	...	...	+	...	...	...	+	.71	.40	+
Do	T4	L	1.58	...	...	...	+	...	...	...	+	.90	1.30	+
Do	T20	L	1.58	...	...	...	...	+	...	+	...	1.02	1.10	+
Do	T22	L	1.34	...	...	...	+	...	...	...	+	1.00	.91	+
Do	T23	L	1.90	...	...	...	+	...	...	...	+	.90	1.73	+
Do	T24	L	1.41	...	...	...	+	...	...	...	+	1.05	1.42	+

Bikar	B14	S	1.61	...	...	...	+	...	...	...	+	1.16	1.47	+
Do	B15	S	1.73	...	...	...	...	+	...	+	...	1.17	1.09	+
Do	B12	S	1.92	...	...	...	+	...	...	...	+	.93	2.46	+
Do	B16	S	1.95	...	...	...	...	+	...	+	...	1.62	1.23	+
Do	B4	S	1.84	...	...	...	...	+	...	+	...	.93	1.78	+
Do	B5	S	1.98	...	...	...	+	...	...	...	+	.60	.98	+
Do	B6	S	1.30	...	...	...	+	...	...	...	+	1.03	.55	0
Do	B7	S	2.51	...	...	...	...	+	...	+	...	1.08	1.21	+
Do	B13	L	2.02	...	...	...	...	+	...	+	...	.81	1.47	+
Do	B11	L	1.92	...	...	...	...	+	...	+	...	.93	2.81	+
Do	B3	L	1.64	...	...	...	+	...	...	...	+	.83	.64	0
Do	B8	L	1.34	...	...	...	...	+	...	+	...	1.07	.91	+
Ailuk	6	S	1.45	+	...	...	...	...	+	...	...	1.27	4/n.d.	+
Lae	14	S	1.68	...	...	...	+	...	...	...	+	1.15	3.80	+
Likiep	J8	S	1.26	...	...	+	...	...	+	...	...	1.06	1.18	+
Do	7	S	1.55	+	...	...	...	...	+	...	...	1.64	1.30	+
Kwajalein	9	S	1.70	...	...	...	...	+	...	+	...	2.03	1.37	+
Do	J10	S	1.79	...	...	+	...	...	+	...	...	1.61	1.28	+
Do	10	L	1.10	...	...	+	...	...	+	...	...	.89	.75	0
Do	J1	L	1.09	...	...	+	...	...	+	...	...	.98	.68	0
Do	11	L	2.36	...	...	...	+	...	...	...	+	2.13	.99	+
Do	J2	L	2.76	...	...	...	+	...	...	...	+	1.63	1.57	+
Do	12	L	1.26	...	...	...	+	...	...	...	+	.97	.39	0
Do	J7	L	1.26	...	...	+	...	...	+	...	...	.99	.36	0
Taka	5	S	1.18	...	...	...	+	...	...	...	+	1.06	1.06	+
Do	J3	S	1.26	...	...	+	...	...	+	...	...	.88	1.16	+
Do	28	S	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	n.d.

1/Mean grain size; 2/S, seaward beach; 3/L, lagoon beach; 4/n.d., not determined.

Table 6.--Coefficient of sorting of Marshall Islands beach sands in relation to major constituents and skewness of distribution

Analyst, Dorothy Carroll

Atoll	Sample No.	Situation on atoll or islet	Sorting	Major constituents					Sorting caused by			Skewness		
				Corals, algae	Fresh Foraminifera	Worn Foraminifera	Mixed assemblage	None dominant	Organisms (Category A)	Agencies (Category B)	Both together (Category C)	Skewness (Sk)	Mean[1] (mm)	Sign of skewness
Do	TW4	L	1.00	...	...	...	...	+	...	+	...	2.20	1.31	+
Ujae	J6	L	1.70	...	...	...	+	...	...	...	+	1.45	1.10	+
Do	13	L	1.00	...	...	...	+	...	...	...	+	.83	.72	0
Ujelang	J4	S	1.87	...	...	+	...	...	+	...	...	2.08	3.06	+
Do	J5	S	1.64	...	...	+	...	...	+	...	...	1.02	1.38	+
Do	J9	S	1.79	+	...	...	...	...	+	...	...	1.06	2.90	+
Do	25	S	1.70	...	...	...	...	+	...	+	...	.73	2.00	+
Do	23	L	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	+
Do	24	L	1.34	...	...	...	+	...	...	...	+	1.12	.45	+
Do	26	L	2.60	...	+	...	...	...	+	...	...	3.66	n.d.	+
Utirik	1	L	1.41	...	...	+	...	...	+	...	...	1.14	.93	+
Do	2	L	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	n.d.
Do	3	L	1.10	...	...	...	...	+	...	+	...	.90	n.d.	+
Do	U5	L	n.d.	+	...	...	...	...	+	...	...	n.d.	7.26	n.d.
Wotho	15	S	2.02	+	...	...	...	...	+	...	...	4.26	n.d.	+
Do	16	S	1.18	...	...	+	...	...	+	...	...	1.01	.73	0
Do	18	S	1.10	+	...	...	...	...	+	...	...	1.03	2.60	+
Do	17	L	1.26	...	...	...	...	+	...	+	...	.98	.48	0
Do	19	L	1.05	...	...	+	...	...	+	...	...	.85	.77	0
Do	21	L	1.22	...	...	...	...	+	...	+	...	.82	.96	0

[1] Mean grain size; [2] S, seaward beach; [3] L, lagoon beach; [4] n.d., not determined.

Table 6.--Coefficient of sorting of Marshall Islands beach sands in relation to major constituents and skewness of distribution

Analyst, Dorothy Carroll

PART IV: UNCONSOLIDATED SEDIMENTS CONSIDERED AS SOILS

by F. R. Fosberg and Dorothy Carroll

The loose unconsolidated sediments are the parent materials of the majority of the soils that develop on atolls. In no place visited in this survey was any soil observed being developed by gradual alteration or weathering in place of consolidated materials, nor has any such soil been found described in the literature on coral atolls (unless breaking down of limestone in mangrove swamps, described for Indian Ocean atolls by Wharton (1883), is regarded as an exception).

A distinction must be made between these sediments, which are practically pure calcium carbonate, and such impure limestones as are laid down adjacent to high land from which they receive an increment of detrital clay and sand. From such impure limestones, soils which are either clayey or sandy will develop through removal of calcium carbonate from the rock. Such soils are common on the coral limestone portions of high complex islands such as the Marianas and Ryukyus. It has not been suggested that any atoll soils are of such a residual nature except by Lipman and Shelley (1924), who suggested that a considerable thickness of limestone has been dissolved away to produce the soil analyzed by them from Rose Island, Samoa. The inadequacy of the sample analyzed and the existence there of volcanic rock of uncertain origin make it futile to discuss this one exception until further study is made of the Rose Island soils.

General character of atoll soils

In general the soils found on coral atolls are pale to gray-brown or black, and sandy to very coarse in texture. Occasional loamy or sandy loam surface layers occur, and less commonly are present as buried horizons. The depth varies, but according to no obvious pattern. In most places sampled consolidated rock was encountered only below 1 meter depth or not at all in test holes dug to between 1 and 3 meters. The material is conspicuously stratified, but the beds of different textures do not commonly correspond well to true soil horizons, which are distinguished by color (as well as chemical, mineralogical, and textural) differences.

Since all these soils are very immature, the horizons are mostly weakly developed and tend to grade into one another rather than being sharply defined. Generally there are only an A1 horizon of varied thickness, darkened by humus, and a C horizon not much altered. In one special type of limited extent an Ao horizon of raw humus and a B horizon of phosphate are characteristic.

Usually the darker and presumably older soils are nearer the center of the islets, if present at all, whereas the lighter ones tend to be peripheral. Ridges of very coarse stony material are common, mostly on the seaward sides of islets. Muck soils of very limited extent are found in depressions and taro pits.

Previous descriptions

There have been various casual references to, and passing descriptions of, atoll soils in the past, as well as the brief analytical study and interpretation by Lipman and Shelly (1924), and a series of short descriptions of soils of the Pacific equatorial islands by Christophersen (1927). Effective study of atoll soils, however, scarcely began before 1950, when E. L. Stone, Jr., visited Arno Atoll, in the southern Marshall Islands, for the express purpose of making soil investigations. His preliminary report (1951a) described in detail fourteen soil types and discussed soil formation in terms of physical and biological factors, as well as the chemical properties and ecological relations of these soils. Two of the soil series recognized by Stone (1951a, p. 19-25), the Shioya and Arno Atoll, plus his "stony and very stony complex" have since been found to be very widespread and most of the soils studied in the present investigation are classified with them. During 1951, investigations were carried out in the Gilbert atolls by Catala and by Cloud, as well as the beginning of the present study in the northern Marshalls. A preliminary report by Cloud (1952), a review by Stone (1953), an extensive report by Catala (1957), and short studies by Fosberg (1954), and Fosberg and others (1956) resulted. These brought out some additional diversity, including low-lying soils with a compact clay-like subsoil in the Gilberts, and the description of the Jemo series of phosphate soils in the Marshalls. Investigations on Raroia, Tuamotus, by Newell in 1952 and on Kapingamarangi, Carolines, by McKee and Niering in 1954 (Newell, 1954a, b, 1956; McKee, 1956, 1958; Niering, 1956, 1963) showed that essentially the same types of soil occur in these islands as were previously described from the Marshalls. No phosphatic soils were found on Raroia, however. Tercinier (1955), describing soils of the low islands of French Oceania, recognized three soil types only, in addition to stony ridges corresponding to the "stony and very stony complex." Of these, the pinkish sandy and gravelly soils immediately behind the boulder ridge and the sandy and gravelly soils along the lagoon shore seem to fall into the Shioya Series, and his stony or stony-gravelly soils from the center of the atoll obviously correspond to rather poorly developed Arno Atoll Series soils.

Most of the above workers seem to be in essential agreement about most of the soil-forming processes, and their reports are drawn upon freely in the present interpretation of the situation in the northern Marshall Islands.

Soil-forming factors

According to Jenny (1941) there are five principal factors of soil formation: parent material, climate, biological activity, relief, and time. Many processes can be identified as contributing to or characterizing the interaction between these variable factors to form soils. Soil development, in most continental and high island areas, presupposes that the parent material is weatherable; that is, that it can be broken down chemically and mechanically to form the mass of material in which plants grow and which we term soil. This weathering goes on everywhere, but in areas where the parent material is of loose sediments it is not as essential as in places where soils must be derived from hard rock. Here in the coral atolls an acceptable distinction can scarcely be made between the loose unaltered sediments which make up the parent material and essentially similar materials which serve as a substratum for plant growth and which are then called soil. However, the alteration and diversification of these materials which have produced and now characterize the various soil types described by previous workers, and which are recognized and discussed below, are definitely the result of certain processes of soil formation. Therefore, they are properly termed soils, though they are very young and poorly developed soils. Especially important among the processes involved are the accumulation of organic material, and the leaching and deposition of mineral materials, particularly calcium carbonate and phosphate.

The soil-forming factors considered important by Jenny (1941) are discussed in their relation to atoll conditions in the northern Marshalls and to the soils that have developed on the atolls.

Parent material

The parent material has been described and commented upon above, (see p. 23), being loose calcareous sediments of varied texture. The degree of alteration varies with the soil concerned. Generally the particles in the blacker layers have become more weathered than corresponding particles in the paler material.

Climate

The features of the climate of the northern Marshalls (see p. 5-6) that are of most significance in the formation of its soils would seem to be the consistently rather high temperatures and complete lack of frost, the amount and distribution of rainfall, the intensity and prevalence of winds from a particular direction, and the incidence of typhoons.

With temperatures ranging continuously between 68° and 95° F, the rate of production and addition of organic matter to the soil is high and the process is not seriously interrupted seasonally. However, the same high temperatures result in rapid and relatively complete decomposition of the organic matter, under most circumstances, and consequent slowness of humus accumulation in the soils. Lack of frost which seriously reduces the populations of decomposing agents in temperate climates and interrupts their activities, tends to accentuate this effect of the high temperatures, as compared with more northern climates.

The relatively high rainfall, tending to increase luxuriance in the vegetation, also brings about the addition of greater quantities of organic matter as well as, in some areas, providing a more favorable medium for some of the organisms responsible for decomposition of this material. It also brings about leaching of soluble constituents at a high rate, as well as the weathering of the particles. The effect of this leaching on accumulation of organic matter is not clear to us. A result that is of more than ordinary interest in the atoll environment is the removal of sea salt that would otherwise accumulate in large amounts from the spray which is carried onto the land by the wind. The large amount of rain also serves to balance the effect of diffusion of salt water into the soil from the surrounding ocean. All the effects ascribed to rainfall will theoretically decrease in intensity as one goes from south to north in the Marshall Islands, as the rainfall becomes less in that direction. Actually, such differences are hard to observe and scarcely show up in our data, as the number of analyses is very small and they were not made with these features in mind. However, the complete lack of dark soils on Taongi (Pokak) Atoll, the driest of the group and that with the sparsest vegetation, may be significant in this connection. The effects of seasonality of rainfall in the Marshall Islands are not apparent, probably because the increase in seasonality is roughly parallel with increased dryness, and the effects of the two would be hard to distinguish.

The only obvious effects of ordinary wind would be in the deposition of sand, carried from the beaches onto the land in the interior of the islets, and the carrying of salt spray in from the breaker zone at the edge of the reef on the windward side. The amount of sand deposition is obviously important, as indicated by the small dunes found here and there, especially piled around the bases of plants. Layers of pebble-free sand in soil profiles are probably to be ascribed to wind, as well as some of the sand in other layers, but so far we have usually not been able to distinguish this material from that deposited by water. The effects of salt spray on the vegetation are apparent in the windward-leeward asymmetry of the profile of the vegetation when viewed from a distance, in the greater development of halophytic features on the windward side, and in eccentric patterns of zonation of vegetation in islets. Whether there is a direct effect on the soil or only an indirect one through the vegetation is not clear.

The effect of typhoons on the soil pattern is gross but of the greatest importance. Plate 32 shows the effect of a typhoon on Utirik islet. The marks of such catastrophic events may be seen practically everywhere. Boulder ridges, classified as stony and very stony complex soils, are a striking feature of most atolls. Denuded areas, of bare rock with only pockets of soil are very common and probably the result of typhoon action. Most areas show soil profiles with buried A horizons. These are probably very largely the result of deposition of sheets of sand and gravel by typhoons. Effects of long duration from inundation by salt water, though they might be expected, have not been noted.

Biological activity

Biological activity will be treated in somewhat more detail, as it is essential for an understanding of the soil-forming processes. Plants and animals are both important.

The luxuriance of the vegetative cover reflects, in an accentuated fashion, the gradient of rainfall from south to north. In the more humid south the cover is very dense, thinning out gradually northward until in the much less rainy Taongi (Pokak) Atoll it presents a distinctly semi-arid aspect. This does not seem explainable on the rainfall figures alone, since the rainfall of Taongi is about that of the luxuriantly green eastern United States, but must depend on the almost perfect drainage combined with high temperatures. The vegetation of the northern Marshall Islands was briefly described on page 24, to which reference should be made.

The influence of biological factors has been described by Stone (1951a, p. 15-18), and the following paragraphs have been taken from his work.

"BIOLOGICAL FACTORS

"Organic Matter

"From previous paragraphs it is already apparent that living vegetation and its disintegrating products contribute greatly to the solution of calcium carbonate by their production of carbonic acid. Through penetration of roots this process may occur slowly even well within large pieces of porous coral. Baas-Becking has called attention to the abundance of algae which on Arno, as elsewhere on the moist tropics, mantle the surface of rocks and even the sand in open groves.

"Apart from the effects on solubility the organic matter itself is of great significance in soil formation. In the absence of the more profound changes that mark mature soils, the presence of organic matter is the principal feature characterizing the atoll soil. It is obviously the principal source of cation exchange capacity. Further, the accumulation of nitrogen parallels that of well decomposed organic matter ("humus") for there is a fixed carbon-nitrogen ratio of approximately 10 or 12 to 1.

"The breakdown of organic remains is carried on in large part by micro-organisms but earthworms are often abundant, and small snails locally so, in the darker soils. The earthworms are presumably significant agents in mixing the surface matter with mineral soil although root growth and decay provides another means of incorporation. Dead woody tissues are generally broken down by termites. In localized areas burrowing crabs accomplish very considerable mixing. Where excessive moisture prevents normal oxidation of organic materials these accumulate giving rise to peats and mucks ....

"Nitrogen Fixation

"Baas-Becking has stressed the possible role of algae as nitrogen fixers and from soil samples collected by him a new group of nitrogen bacteria, *Beijerinckia*, has been isolated by Derx. *Azotobacter* has not been reported in atoll soils but would be expected in this habitat. /Later found in Stone's samples by Lochhead, see Stone (1953), and by Stevenson (1953)./

"On Arno legumes are common and nodules were observed on *Vigna marina*, *Sophora tomentosa* and *Canavalia sericea*. On the latter they occur on the roots at some distance from the root crown and hence they may be easily missed. The *Vigna* seems particularly important for it forms thick masses in the open groves and extends aggressively onto sand beaches, old dwelling sites and burned areas. The two species of *Canavalia*, though less abundant, are vigorous vines in lightly shaded areas. *Intsia bijuga* is the only leguminous tree but its abundance in the original forest cannot be estimated accurately now.

"Seabirds

"Throughout the dry islands of the Pacific nesting seabirds have created guano deposits and highly nitrogenous soils. Under wet conditions such accumulations do not remain long but the numerous areas of phosphate rock are generally considered to have originated beneath such guano areas. As mentioned, the phosphate was precipitated as the insoluble calcium salt when carried into calcareous material beneath, whereas the soluble nitrates were washed away. The resulting product is usually well cemented although unconsolidated brown sands may occur with the rock. Phosphate rock, guano, and soils strongly influenced by guano occur only where large numbers of seabirds congregated for long periods. Even away from these areas, however, the birds must have a very considerable effect on the soil. They are common in small numbers on many islands where they roost and nest...; feeding along the beaches and at sea they are the only significant agents adding to the land from the fertility of the sea."

Another biological activity not to be underestimated is the boring activity of microscopic blue-green algae which seems general in any limestone surface exposed to air for a considerable length of time. So appreciable is the breakdown of limestone by this agency that Nesteroff (1956) regards it as accounting for the greater part of both intra- and supra-tidal erosion of limestone. These algae must also add organic matter and possibly also nitrogen to the soil.

Relief

The relief of the atolls is negligible, the highest point seen being only some 25 feet above mean sea level. Nevertheless, drainage is rapid. Actually, since drainage has little or no relation to relief, it should in these situations be considered a separate additional factor, distinct from relief. The relief is mainly the result of piling up of loose materials, rather than of erosion of elevated land. There seems to be little or no relation between slope and soil type, but where the bottoms of depressions approach the water table there are in most cases special soils, either peat or muck. The higher areas are generally either boulder ridges or sand dunes. On the boulder ridges the soil is classified as stony and very stony complex; on the dunes it is generally Shioya. However, these seem to be more depositional than related to relief.

Drainage

The drainage in the atoll soils is mostly either very good or extremely poor (see p. 23), the coarse texture permitting rapid percolation of water through most material that lies at all above the water table. The water table is essentially mean tide level and fluctuates slightly with tidal changes.

Two processes related to the good drainage above the water table are of general significance. One is the solution, and removal by leaching of solutes, that accompanies the movement of water over the surfaces of the particles. The other is the migration downward of any very finely divided material that exists in or is deposited on the upper layers. This probably accounts in part for the low proportion of finer inorganic fractions in these soils. Also important here may be sorting and removal during the deposition process, also probably an original deficiency of fines.

Time

The time factor is difficult to assess, as the actual age of a soil is seldom known. However, the fact that calcium carbonate has not been removed to any great extent, at least differentially, from the upper layers of these soils, even in some cases under the influence of water that has percolated through an acid peaty layer, is one indication that these soils are relatively young. The difference between the actual and theoretical calcium percentages is so small and so obscured by the varied magnesium percentages that it cannot be regarded as indicating much or perhaps any differential leaching of calcium carbonate in any particular layer. It is commonly found, too, that the calcareous remains of the various reef organisms are readily recognizable throughout the profiles and have not been strongly affected by solution. Foraminiferal tests from soils are shown in plate 33. The weathering exhibited by these tests shows that some solution does occur, but not enough to make them unrecognizable. The hardness of the ground water also indicates solution, but not the amount.

It seems fairly clear that the Shioya soils are very young, grading imperceptibly into almost completely unaltered parent sediments. Almost no organic matter has accumulated in these light-colored soils. They grade into the darker Arno Atoll series, with much higher organic content and also more weathering of calcareous particles. There is undoubtedly a greater time involved in the formation of the blacker soils, but what the actual or relative time figures are is at present impossible to say. The variable nature of the other factors involved makes it highly unlikely that there is anything like a linear relation between amount of organic matter and time. The clarification of this relationship would be of great interest but will undoubtedly require more information than is presently available. Perhaps radiocarbon determinations of the organic carbon at different levels may give some approach to an absolute time scale.

The thickness of phosphate layers in the Jemo soils and the degree of replacement of calcium carbonate by calcium phosphates is undoubtedly also related to time. Certain of the layers analyzed are completely altered to phosphorite, but differences in bird populations and in luxuriance of the Pisonia forests involved in the phosphate formation again suggest that no linear relation is possible.

Until the detailed chemistry of the percolating waters that carry out the leaching process is known it will not even be possible to say what theoretical rates of change in proportions of relatively insoluble substances are likely. All that can be said now is that the differences in amount of most of them found in our analyses are too small to be very useful in interpreting the effects of the time factor in the formation of atoll soils.

Composition

Atoll soils resemble the beach materials of the islets in grain size distribution and in chemical and mineralogical composition. The grain size distribution of the soils was given in table 5. Table 7 sets out the most prevalent grade sizes found in the principal types of soil. The relation between the size distribution in beach sands and soils is shown in figure 28.

Table 7.--Distribution of modal grade size of calcareous material in soil profiles as percentage of total samples sieved

	Grade size (mm)						
Soil series	+8.0	+4.0	+2.0	+1.0	+0.5	+0.25	+0.125
Shioya (46)*	32	2	2	11	21	28	2
Arno Atoll (23)	18	4	4	30	39	4	...
Jemo (7)	28	...	...	57	14	...	...
Miscellaneous (19)	42	...	...	26	21	10	...

*/ Number of samples sieved.

It has been observed by Stone (1951a, p. 14) that many soil profiles are composite and have layers of black organic material at different depths.

Chemically the parent materials consist almost exclusively of calcium carbonate with varying small amounts of magnesium carbonate, depending on the type of organisms present. Minor amounts of other

Table 8.--Chemical composition (in percent) of calcareous reef and lagoon constituents, and of composite sediment samples (from Emery, Tracey, and Ladd, 1954, table 11, p. 67)

Analysts: C. M. Warshaw (Nos. 1, 2, 5, 6, 7, 9); A. C. Vlisidis (Nos. 3, 4, 10, 11, 12, 13); W. W. Brannock (Sr determination); J. M. Axelrod (X-ray determination of minerals)

	Foraminifera		Halimeda		Calcareous red algae			Corals	Sediments				
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	0.20	0.12	0.50	0.14	0.18	0.24	0.10	0.06	0.12	0.16	0.20	0.20	0.20
$(Al,Fe)_2O_3$	.30	.22	.30	.34	.40	.46	.34	.06	.36	.28	.26	.28	.18
MgO	5.52	5.67	.32	.38	8.01	8.25	6.73	.24	4.95	1.32	2.26	.82	.54
CaO	46.90	47.86	54.51	53.25	42.20	41.85	42.91	53.08	47.78	52.28	50.31	52.84	52.64
SrO	.18	.16	.90	.87	.24	.24	.22	...	.28	.72	.46	.82	.73
CO_2	42.64	43.16	42.66	41.46	41.08	40.43	39.75	41.68	42.36	41.57	41.65	41.60	41.28
Acid-soluble SO_3	.32	.68	.16	.25	.70	.64	.70	(?)	.44	.34	.55	.29	.37
Acid-insoluble organic	.26	.16	...	.15	1.27	1.60	2.01		.28	.17	.21	.16	.32
Water-soluble organic	.45	.87	...	...	1.98	2.73	2.47	3.21	...	...	...	...	...
Water	.40	.50	.20	.30	1.53	1.48	1.52		.48	.28	.28	.24	.44
Total	97.17	99.40	99.55	97.14	97.59	97.92	96.75	98.33	97.05	87.12	96.18	97.25	96.70
Acid-insoluble inorganic	0.18	0.09	...	0.38	0.35	0.38	0.36	...	0.12	0.20	0.05	0.43	0.25
Minerals[1]	C	C	A	A + little C	C	C	C	A	C + little A	A + little C	A + C	A + little C	A + little C

[1] C, calcite; A, aragonite.

1. Picked Foraminifera (Calcarina spengleri). Lagoon beach, Bikini.
2. Picked Foraminifera (Marginopora vertebralis). Lagoon beach, Bikini.
3. Picked unweathered Halimeda segments.
4. Picked weathered Halimeda segments.
5. Lithophyllum (Porolithon) gardineri.
6. Lithophyllum craspedium.
7. Porolithon onkodes.
8. Average of 15 analyses of madreporarian reef corals (Clarke and Wheeler, 1917).
9. Coarse foraminiferal beach sand, Bikini (sample Bik. 3).
10. Fine beach sand, Bikini (sample Bik. 5).
11. Medium sand, lagoon, 69 feet, Bikini (sample Bik. 51)
12. Medium sand and Halimeda debris, lagoon, 108 feet, Bikini (sample Bik. 713).
13. Halimeda debris, lagoon, 156 feet, Bikini (sample Bik. 548).

constituents such as calcium phosphate, calcium sulfate, and aluminum and iron oxides may also be present. Table 8 gives the composition of some of these reef-forming organisms.

Mineralogically both forms of calcium carbonate, aragonite and calcite, are present, the quantities depending on the dominant organisms. In addition, there is secondary and local enrichment of phosphate in the form of the mineral apatite.

Classification of soils

Stone's classification of atoll soils, with certain alterations, serves very well for the northern Marshall Islands, as for most other atolls studied so far. This classification was adapted for the northern Marshall Islands by Fosberg (1954) from whom the following paragraph as well as the introductory paragraphs under each soil unit are quoted.

"Areally, four principal units are easily definable on the atolls. They are (a) essentially unaltered sands and gravels; (b) stony and very stony complex; (c) Shioya series; and (d) Arno Atoll series. In addition to these, the Jemo series is widely distributed, though much smaller in area. Minor units are the muck soil found in taro pits, mangrove peat, and one or two local types so far known only from Arno Atoll. Exposed limestone reef-rock or beach-rock is common, usually in narrow peripheral strips and on denuded areas on the windward sides of atolls. This rock can scarcely be considered a soil, though it often serves as a substratum for one species of tree--Pemphis acidula. Where there are small pockets of sand, Portulaca and Lepturus may also clothe some of these bare rock surfaces."*/

Only a rough generalization may be made of the areal distribution of these categories, but the accompanying schematic diagram of an atoll islet (fig. 29) will serve to illustrate the general pattern.

All the atoll soils are relatively immature, the Shioya series being little modified from the parent material, the Arno Atoll series more modified, and the Jemo series even more so. However, these three are not necessarily related in a linear developmental series. In terms of profile nomenclature the Shioya and Arno Atoll series are "A-C soils" with an A_1 horizon (zone of incorporated organic matter) and usually a narrow A_3 (transitional) horizon passing directly into the relatively unaltered material, the C horizon. As a group, these two series are a tropical equivalent of the "humus-carbonate soils" of European workers (see Stone, 1951a, p. 19). The Jemo series, on the other hand, is an A-B-C soil with an A_{oo}(litter) horizon and an A_o (partly decomposed plant remains) lying directly on a B (deposition or accumulation) horizon, which in turn lies on the relatively unaltered material or C horizon.

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*/ Subsequent observation by Fosberg in 1956 suggests the existence of still another soil series, as yet undescribed and inadequately studied, on two or more of the northern Marshall Islands not visited during the 1951-1952 survey. This seems to be associated with a vegetation made up principally of Cordia subcordata Lam. which is not extensively developed on the atolls visited in 1951-1952. It was observed on Ailinginae and Rongerik Atolls, but time was not available for careful profile description and collection of adequate samples.

In this investigation chemical analytical data are given for 54 profiles or partial profiles comprising 100 samples. These are distributed among different soil types as follows (the proportions representing the different series are accidental and bear no relation to the relative abundance of the series in the field):

Unaltered sands
  2 profiles comprising 2 samples.
Stony and very stony complex
  No samples.
Shioya series
  7 profiles comprising 13 samples.
Arno Atoll series
  10 profiles comprising 28 samples.
Jemo series
  27 profiles comprising 46 samples.
Miscellaneous
  8 profiles comprising 11 samples.

These six categories will be described individually, with the chemical features summarized in tables 9-14. This will be followed by discussions of atoll soil development and of the chemical characteristics of atoll soils. Locality and descriptive data for all profiles analyzed are presented in appendix II. Profiles sampled but not analyzed are mostly omitted from the appendix but their localities are indicated on figures 16-18.

Soil units and series--characteristics and chemistry

Unaltered sand and gravel

"Unaltered sand and gravel, made up commonly of foraminiferal tests and the pulverized or waterworn skeletons of other animals and calcareous algae, are of wide distribution. They occur as bars on the reefs, spits, and narrow places on the ends of islets, beaches, and areas of dunes, most frequently on the lagoon coasts. They are white to pink, or even orange-pink. A number of kinds of plants grow in such substrata with no apparent inconvenience" (Fosberg, 1954).

Representing this are two samples, 39 and 40, both from Ailuk Atoll. Sample 39 is from the center of an almost unvegetated sand-bar on the windward reef. Considerable local variation in texture was observed but was not represented in the sample, which was taken from one spot. Sample 40 is from the windward base of a sand dune on Enejelar islet. The material in both represents only the surface layer of the profile.

Chemical analyses of major constituents are presented in table 9. These analyses represent, at least in some measure, the parent material and thus can be used as a basis of comparison for soils which may have been chemically altered during soil formation. The soil has a pH of 9.4. There is very little difference in the percentages of the constituents analyzed in the two samples, and the average composition is as follows: Calcium, 36.6 percent; magnesium, 1.8 percent; sodium, 0.3 percent; potassium, 0.03 percent; phosphorus, 0.03 percent; total soluble salts, 0.15 percent of which only one-fourth is sodium chloride.

Stony and very stony complex

"The unit termed stony and very stony complex by Stone (7 /1951a/, pp. 29-31) is made up principally of the cobble- and boulder-ridges and boulder-flats, which are a common feature of most atolls, especially in areas visited by frequent storms. Most of them, but by no means all, are found on the seaward sides of islets, sporadically distributed, but with some preponderance on the sides from which the storm winds most often come. A few such ridges are found behind lagoon beaches. These areas are commonly 100 m or less in width, but some of them may be much wider. Sometimes a whole islet is of this nature. The material is mostly coarse angular or water-worn fragments, sometimes well sorted, often extremely heterogeneous in size. The interstices may be filled with sand and small gravel, they may be empty, or they may have a soil that is black, with a high organic content, near the surface. The boulders and cobbles are white, but wherever exposed they become gray to black, owing to microscopic blue-green algae in their surface layers. This stony ground supports a thick scrub or forest, in some places becoming tall and luxuriant. Coconuts may be planted here, but these are usually the last large areas to be planted. The /coconut/ trees seem to do well except where the climate is too dry, as in the extreme northern Marshalls, or where the land is too narrow. Narrow necks and points of land are apparently too saline for proper development of coconut trees" (Fosberg, 1954).

No analytical data are available for this unit.

Shioya series

"The Shioya series in the Marshall Islands consists of grayish brown sands or gravels, rarely loamy sands (or even silts), that are only slightly weathered and with a very low organic matter content. It was first described (6)/Stensland and others, 1949/ on Okinawa, Ryukyu Islands, for soils developed on emerged old beach deposits of calcareous sand; later the term was applied to similar soils on Saipan, and then by Stone (7 /1951a/, pp. 19-22) made to include soils of this nature from Arno Atoll. On atolls the Shioya lacks the considerable percentage of quartz sand found in some of the Shioya sand of Okinawa, but the difference is probably not significant. This is by far the commonest and most wide-spread soil found on coral atolls. It naturally supports most of the mixed forest, several other forests types, and the

Lepturus grassland vegetation characteristic of atolls" (Fosberg, 1954).

This is a well-drained alkaline soil formed principally on calcareous sands and gravels, largely but by no means always medium to fine grained. It is typically marginal on the islets, developed toward ocean and lagoon coasts and on the ends of the islets, much less so and tending to be replaced by the Arno Atoll soils in the central parts (fig. 29). There is a transition zone between Shioya and Arno Atoll series.

A characteristic profile of the Shioya loamy sand from Arno Atoll is described by Stone (1951a, p. 20) as follows:

0 - 7"	Friable loamy sand, dark gray (10YR-4/1) in color when moist, single-grained or weakly aggregated. pH 7.8.
7 - 8"	Transitional.
8 - 40"+	Single-grained loamy sand, pinkish white (7.5 YR-9/2), composed of Foraminifera and ground shells, coral and Halimeda fragments. pH 8.4.

Color names and notations are according to the Munsell system.

A Shioya gravelly loamy sand and a Shioya sand have also been recognized and described from Arno Atoll, southern Marshall Islands. They differ from the Shioya loamy sand principally in the size of the calcareous parent material.

Although these several textural types have been described from the southern Marshall Islands, and although much textural variation is apparent in the present material and from field observations, for the purposes of the present report no textural types have been distinguished. It is felt that a more thorough sampling would be necessary to give such classes meaning.

Shioya soils were observed on practically all islets of all atolls visited, and samples of soil from Shioya profiles were obtained from all of these atolls except Kwajalein (see maps of islets showing sample localities, figs. 16-18; and Appendix II, p. 101). These were not all analyzed but at least some chemical analytical information is available for 13 samples from 7 Shioya profiles. Unfortunately only three reasonably complete profiles are represented by these data (see table 9). Of these three profiles one is from Lado, Likiep Atoll and the other two are from Wotho, Wotho Atoll. In addition, samples of surface layers were partially analyzed from profiles from Taka, Taka Atoll.

Of the major constituents, calcium ranges between 33.7 and 37.8 percent, generally increasing somewhat downward. Magnesium ranges between 0.8 and 2.7 percent, consistently increasing downward in the profile. Sodium ranges between 0.18 and 0.31 percent. Potassium is constantly between 0.02 and 0.05 percent and phosphorus is similarly low, from 0.02 to 0.21 percent.

Probably because the islands are exposed constantly to the influence of spray blown in from the ocean, the total soluble salt content is high, ranging between 0.02 and 0.49 percent, on the basis of dry weight. Assuming a moisture content of at least 25 percent in the soils as they occur naturally, this would indicate salt concentrations in the soil solution ranging from about 0.1 to 2.0 percent, varying seasonally. Most of these concentrations, especially the higher ones, would probably have a severe limiting effect on plant growth and might well account, at least in part, for the impoverished flora of atolls, especially the drier ones, as has been suggested earlier (Fosberg, 1949). Curiously enough, the higher sodium chloride contents, calculated from the chloride percentages, are found to correspond to the lower range of total soluble salts. The correlations, however, are not very good and possibly little importance is to be attached to this phenomenon.

Few determinations of organic carbon were made for this series, as, in general, soils of this series are low in organic matter and there is no peaty layer. Hydrogen ion concentration ranges between pH 8.06 and 9.67, determinations made on stored material. The only pH below 8.3, normal for calcium carbonate solutions under ordinary conditions, is in a surface layer where organic matter would be expected to have some influence, though in small amount. Higher figures doubtless reflect the presence of magnesium carbonate. Samples 126 and 129, showing the highest magnesium content and the highest pH, contain about 20 percent and 50 percent respectively of fresh foraminiferal tests, some species of which contain a high proportion of magnesium carbonate (table 8).

Arno Atoll Series

"The Arno Atoll series (7 /Stone, 1951a/, pp. 22-25) is composed of black or dark brown (values 1-4 in Munsell system) loamy sands and sandy loams with usually some increment of gravel. The organic matter content is high /16 to 32 per cent in original analyses by Stone (7 /1951a/, table 2)/ for tropical soils. The origin of these soils is obscure and may well be different in various occurrences. In some atolls the soils of this series seem to be correlated in occurrence with a history of intensive human activity (Utirik, Ailuk, Arno?), but in others (Jemo) definitely not. These soils occur in fairly large patches in the interiors of sizeable islets. They usually support coconut plantations at present. Little is known of their original vegetation. In certain areas of this type (Arno, Ailuk) the coconut trees become unhealthy and die early, possibly as a result of nutrient deficiency (8 /Stone 1951b/, p. 11-12) brought about by overcropping of copra (dried coconut meat)" (Fosberg, 1954).

This is a well-drained, dark-colored, calcareous soil formed on old beach and dune sands under vegetation in the island interiors. A representative profile from Arno Atoll is described by Stone (1951a, p. 22) as follows:

0 - 11"	Highly organic, granular loamy sand or sandy loam, somewhat plastic when worked. Black when moist, very dark gray (10YR-3/1) when dry, heavily flecked with lighter sand particles. pH 7.5. Earthworms abundant.
11 - 13"	Abrupt transition from above to--
13 - 21"	Single-grained, light-gray loamy sand stained with organic matter, becoming white (10YR-8/2) at a depth of a few inches. pH 8.4.
21-54"+	Friable, pinkish white (7.5YR-9/2) limesand becoming coarser at 40 inches.

The above description is of the Arno Atoll loamy sand developed on sand-grade material. A similar soil from Arno Atoll with coarser parent material has been called the Arno Atoll gravelly loamy sand. Types based on texture have not been distinguished in the present report.

Soils interpreted as belonging to the Arno Atoll series were observed on Taka, Utirik, Ailuk, Jemo, Likiep, Ujelang, Wotho, Ujae, and Lae Atolls, and samples representing profiles or partial profiles were obtained from all these (see maps of islets showing sample localities, figs. 16-18, and Appendix II).

In the laboratory information was obtained on organic matter, pH, salinity, and general chemistry for 28 of these samples (see table 9) but the data by no means are complete for all the samples.

Of the major constituents, calcium ranges from 32.6 to 38 percent, the surface samples usually containing 2 to 4 percent less than those from the lower layers, as might be expected from the amounts of organic matter present in the upper layer. Profile 27, from Jemo, is exceptional in its very high organic matter and phosphorus and unusually low calcium. It is perhaps not correctly placed in this series, but further investigations on soils in similar situations, in close association with soils of the Jemo series, will be required to clarify the disposition of this somewhat anomalous profile. The magnesium content, from 0.5 to 2.8 percent, increases from the surface layer downward. Variation in magnesium content could be introduced by the varied proportions of different calcareous organisms with differing amounts of magnesium carbonate in their skeletons, but the consistent increase in magnesium from upper to lower layers could scarcely be due to this cause. Estimates of proportions of different organisms making up the different layers show no such regular increase downward of those organisms known to contain much magnesium carbonate. Such is Calcarina spengleri, one of the Foraminifera common in these sediments, which commonly has about 3.5 percent magnesium in solid solution in the calcite structure. For example, in profile 1, samples 39 and 40 have similar proportions of different organisms but differ (1.1 compared with 1.8 percent) in magnesium content. In profile 2, the upper layer, containing abundant worn Foraminifera, has only 0.9 percent magnesium;

in the fourth layer, sample 44 has a preponderance of worn Foraminifera with coral and algae, and 2.3 percent magnesium, whereas in 45, where the Foraminifera are negligible, but also with coral and algae, the magnesium content is also 2.3 percent. In profile 5, samples 48 and 49 each contain about 75 percent Foraminifera, with expected high percentages of magnesium 2.3 and 2.5, respectively. Original composition undoubtedly accounts for much of the variation, but the regular increase downward suggests that leaching of magnesium may have been more intense toward the surface. This would not be unexpected.

The surface layer contains from 0.14 to 2.00 percent phosphorus (omitting from consideration profile 27, which has enormously more) and the lower layers, 3 and 4, contain from 0.02 to 0.52 percent. Potassium ranges from 0.01 to 0.05 percent, excepting for sample 66, in profile 27, which has 0.07 percent.

Organic carbon in the surface layer ranges from 2.88 to 6.01 percent (excepting the anomalous profile 27), and falls off rapidly in the lower layers so far as can be determined from the rather few analyses and the lack of dark staining of the calcareous material. Carbon/nitrogen ratios range between 15 and 28 in the surface layers.

The hydrogen ion concentration is uniformly lowest in the surface layers, from pH 7.30 to 8.35, and consistently increases downward, to an extreme of 9.47 in sample 60 in profile 18. Total soluble salts range from 0.03 to 0.85 percent (except for profile 27, with higher percentages which may have resulted from accidental contamination by sea water). The soluble salts are mostly surprisingly high, considering that the samples come from the interiors of the islets.

Jemo series

This series, described by Fosberg as a result of observations in the Northern Marshall Islands, usually consists of "a layer of organic matter resting on a phosphatic hardpan underlain by loose, essentially unaltered or somewhat darkened lime-sand or gravel" (Fosberg, 1954, p. 101). This, or similar soils, has been observed on a number of central and western Pacific atolls and undoubtedly is what has been exploited as "guano" on many of the more moist atolls of the Pacific. The total area of these soils is not large, but they are of extreme ecologic and pedogenic interest.

A typical Jemo profile (from Fosberg, 1954, p. 104) may be described as follows, from an old Pisonia forest in the interior of Jabwelo (Jaliklik) islet, Bikar Atoll (profile 166 of present paper).

A_{00} horizon	6.0 - 5.5 inches	Loose twigs and leaves of Pisonia grandis, somewhat guano-stained.
A_0 horizon	5.5 - 0 inches	Dark-brown, fibrous or spongy raw humus. Transition to B horizon abrupt.

B horizon	0 - 6.0 inches	Brown salt-and-pepper appearance, very well consolidated. Transition to C horizon abrupt.
C horizon	6.0 +	Loose pale sand mixed with rubble; depth undetermined.

The essential feature of these soils is the existence of an A horizon of a dark-brown to black organic matter, similar to the "raw humus" or "mor" found under northern coniferous forests and on heath lands, spongy or peaty in texture and lacking visible mineral constituents. Usually this is directly underlain by a B horizon of indurated phosphatic hardpan, but in some variants this is absent or, rarely, replaced by nodular phosphatic material. Under this the material typically resembles a Shioya soil.

This soil series seems to be consistently associated with existing or former forests or groves of *Pisonia grandis*, a common atoll tree. Its existence is interpreted as a direct result of the coincidence of large colonies of fish-eating birds roosting or nesting in stands of *Pisonia* trees. The humus which accumulates under *Pisonia* trees is highly acid, at least compared with the ordinary calcareous soils, ranging from pH 4 to pH 6 in reaction. When the guano, largely composed of finely divided calcium phosphate from fish bones, is deposited on the surface of this humus layer and washed by rain down into this acid material, it goes into solution and is carried on down through the organic layer. The high phosphorus figures in the analyses of the organic layers for this series are fair evidence of this. When this acid phosphate solution percolates down into the layer of calcareous soil beneath, it is neutralized and the phosphate comes out of solution as a cement, stained brown by humus, which indurates the loose calcareous material. As the resulting hardpan is subject to further percolation by the acid phosphate the grains of calcium carbonate composing it are gradually replaced by calcium phosphate in the form of apatite. Thus for some samples the analyses correspond to almost pure apatite.

Soluble salts were only determined for five samples. Two of these, both from layer 1, contain more than 2 percent total soluble salts, but the content seems to be quite variable, as two others contain between 1 and 2 percent, and the fifth only a negligible amount. These few analyses could scarcely give an adequate picture, as even in the same place soluble salts might at one time be concentrated in the surface organic matter by nitrification and evaporation, and at another time they might be leached out by rain water and removed through the porous calcareous material in the lower horizons.

Amounts of calcium, magnesium, sodium, potassium, and phosphorus are available for five profiles, three from Bikar Atoll and two from Jemo (table 9). At the surface the amount of magnesium and calcium varies inversely with the amount of organic matter present. This is well illustrated by profiles 153 and 166 from Bikar and profile 25 from Jemo. The surface peaty layers of the two profiles from Bikar contain between 7 and 8 percent calcium with about 55 percent organic matter, whereas the surface layer of the profile from Jemo with only about 35 percent organic matter contains 16.5 percent calcium.

The magnesium content varies similarly, but this variation is in part due to the quantity of the different kinds of calcareous organisms present. Some data on chemical composition of the reef organisms forming these atolls are given on page 121 and tables 3 and 8. Magnesium content depends on the presence of organisms consisting of calcite rather than of aragonite.

The chemical data obtained for the Jemo soils include spectrographic determinations of the trace or minor elements in 31 samples representing 18 soil profiles. These were done in two series reported in different terms, one set including elements not determined in the other. For this reason two tables, 10 and 11, have been prepared to present these results, which have been recombined into a third (table 12) showing the range and frequency of occurrence of the minor elements.

Some of these elements are known to be essential for plant growth and the concentrations of some of them are surprisingly low, considering the luxuriance of the vegetation on these islands. It is clear that at least certain species of plants are adapted to securing their requirements of these elements from soil solutions of extremely low concentration. The most frequent of these minor elements are: boron, chromium, copper, manganese, strontium, iron, and barium. The least frequent are: silver, cobalt, molybdenum, and yttrium. Those with largest amounts are: iron, silicon, and strontium. Those with smallest amounts are silver and cobalt.

Miscellaneous soils

Analyses of the upper layers of a number of miscellaneous soils that do not fit well into any of the named soil series show unusually high content of organic matter, when compared with other northern Marshall Island soils except the Jemo series. Determinations of organic carbon and pH are presented in table 13. A rough correlation between amount of organic matter and acidity shows up in these analyses, and is illustrated by the curves in figure 30. It will be noted that the main deviation is in a soil from a coconut grove, where the organic matter is largely from decomposed coconut husks, leaves, and other trash. The acidity in these soils probably may be ascribed mostly to humic acids, but in the taro pits the soils also smell somewhat of hydrogen sulfide, so some of the acidity may come from hydrogen sulfide produced under anaerobic reducing conditions in the muck in these pits. This general correlation of organic matter and acidity, even in a calcareous environment, is in line with the similar relationships shown in the Arno Atoll and Jemo soils (table 9).

Summary of chemical information

From an examination of the tabulations of analytical results presented in tables 9 to 13, the following summaries were obtained. Certain marked trends are pointed out, but owing to the inadequacy of the sampling no special significance is necessarily to be attached to these. They do indicate areas where future investigations might profitably be concentrated. A summary of the chemical information is given in table 14. This, however, is of limited value except to suggest trends, as the layers are not strictly comparable.

Shioya soil profiles

Organic carbon is usually less than 3 percent (maximum 3.08 percent). Phosphorus is 0.2 percent or less, highest in layer 1 and about equal in layers 2 and 3. Averages for layers 1-3, respectively: 0.15; 0.03; 0.03 percent.

Potassium content is always low, 0.02 to 0.05 percent.

Magnesium content consistently increases downward. Averages for layers 1-3, respectively: 1.09; 1.6; 2.2 percent.

Calcium content shows no significant trends. It varies between 33.7 and 37.8 percent with almost this variation within layer 1. If the whole soil were calcium carbonate the percentage would be 40.

Total soluble salts range from 0.04 percent to 0.49 percent with no order nor preponderance nor discernible trends. Salinity in terms of chlorides converted to sodium chloride shows no definite trend except that high total soluble salts seem to show low salinity and low total soluble salts, high salinity. We have no explanation for this except the possibility that the high percentages of soluble salts may represent sulfates, lacking in the others, and that the salinity variations may be due to sea spray.

Arno Atoll soil profiles

Percentage of phosphorus is roughly related to percentage of organic carbon, but layers showing no black staining were not analyzed for organic carbon; these are presumably less than 1 percent. Phosphorus decreases downward except where there are evidences of buried A horizons, in which cases the phosphorus in the buried A layer is somewhat higher than the C horizon layer above it.

Except for profile 27, layer 1 varies between 0.13 percent and 2.0 percent phosphorus. Averages for layers 1-4, respectively, are: 0.63; 0.30; 0.15; 0.04 percent. Profile 38, which is in an area of Ailuk similar to the "laora" areas of Arno Atoll (Hatheway, 1953, p. 60; 1957, p. 1-3), shows 0.34 percent in layer 1, which is not especially low, but 0.04 percent in layer 3, which is quite low.

Organic carbon is quite variable in layer 1, 2.88 to 6.01 percent (or 11.0 percent in profile 27), and falls off in lower layers (so far as analyzed and assuming less than 1 percent for uncolored layers).

Calcium content is lower in layer 1, but not conspicuously except in profile 27, where it is 23.5 percent. In other layers it is between 35 and 37 percent (except in profile 27, where layer 2 shows 29 percent). The lower percentage of calcium in layer 1 is probably related to high organic content.

Magnesium content generally increases downward. Exceptions are sample 81, from layer 4 of an unusual silty material, where it is very low compared with layers analyzed above it; samples 49 and 50, layers 3 and 4, where the percentages are very close, 2.5 and 2.4 percent; and sample 39, where there seems to be less difference in appearance and color than is usual between the layers of the profile. Averages for layers 1-4, respectively, are 1.02, 1.75, 2.00, and 2.08 percent.

Potassium is uniformly low, ranging between 0.01 and 0.07 percent.

There seem to be no systematic relationships in the percentage of total soluble salts, in the salinities or in the percentage of sodium. Profile 27 shows generally a very high percent of total soluble salts and a very high salinity in all layers, but not a strikingly high percentage of sodium except in layer 2. From the percentage of sodium in layers 3 and 4 and the sodium chloride in total soluble salts, there must be chlorides other than sodium chloride present in quantities.

Examination of the figures for profile 27, from Jemo, shows that it is aberrant, chemically, in many respects. This profile is either unusually high or unusually low in every constituent for which there are figures in one or more layers, as is indicated in the comments in the above paragraphs. For this reason this profile was omitted in calculating table 14. These considerations, as well as the field relations, suggest that it would be best to exclude this soil from the Arno Atoll series. As it occurs on Jemo on land presumed to have formerly been occupied by Pisonia groves, and where pieces of phosphate rock are occasionally found, it is probable that this is a Jemo series soil modified by cultivation. It may be significant that the other Arno Atoll series profiles for which chemical data are available are all from inhabited islands. Those from Taka, which is uninhabited, were not analyzed chemically.

Jemo Soil profiles

Organic carbon in layer 1 ranges from 19.92 to 34.71 percent. Much less is present in the lower layers, but was only determined in one sample of layer 3 where 2.89 percent organic carbon was found.

Phosphorus is high, ranging from 1 to 6.8 percent in the raw humus layer (one sample had a lower figure), much higher in the hardpan layer, ranging from 3 to 13.4 percent, and generally lower in layer 3, except in one profile where the percentage is greater. The average phosphorus content in the hardpan is about 7.4 percent. The phosphorus figures determined by rapid chemical methods (Shapiro and Brannock, 1956) and by spectrographic methods differ markedly; for example, figures of 12 and 10 percent, 5 and 7.9 percent, respectively, were reported for the two sets of samples. For such percentages of phosphorus as are discussed here the rapid chemical analysis method is considered the more reliable.

Leaves of Pisonia growing in this soil on Bikar contained 0.2 percent phosphorus in dried, and 0.5 percent phosphorus in fresh leaves. These figures, however, may not be significant because of possible undetected spatterings of guano.

Calcium content in layers 2 to 4 is between 31.3 and 36.2 percent, which is generally about the content in the more or less unaltered parent material. However, where there are comparable figures in the same profile, that for layer 2 is slightly lower. Probably this would be due to a certain amount of leaching, but it could possibly reflect a somewhat lower calcium ratio in the mixture of phosphates compared with that in calcium carbonate. As the exact composition of the phosphate mixture is not known, this remains purely speculative. The surprising thing is the large amount of calcium, 2.5 to 16.5 percent, average 8.3 percent, in the humus layers. This must be in the form of calcium phosphate, as no carbonate is likely in view of the low pH. However, as the amounts of calcium only roughly parallel those of phosphorus, the variation may be accounted for by assuming variation in the composition of the mixtures of phosphates.

Potassium in layer 1 is substantially higher (0.06 to 0.28 percent, average 0.13 percent) than in the Shioya and Arno Atoll soils and almost twice that in layer 2 of the Jemo profiles. In general, potassium seems either to be accumulated in the humus layer or to be added in substantial amounts in the guano that is deposited on the surface.

Magnesium generally increases downward but not as regularly as in other soil types. In one profile there is no detectable magnesium in the humus layer. In the others magnesium ranges from 0.16 to 0.46 percent in this layer.

Sodium content shows no discernible trends. Total soluble salts range from 0.11 to 2.55 percent, but only a very few analyses were made. The proportion of sodium chloride is high in the humus layers with high total soluble salts, and lower where total soluble salts are low, but there is no systematic relationship. This is the reverse of the condition in the Shioya series.

Iron is present in small amounts, ranging from 0.002 to 0.02 percent in layers 2, 3, and 4, but in all profiles the percentage in layer 1 is much higher, ranging from 0.02 to 0.2 percent. This suggests that Pisonia trees possess the ability to concentrate iron in the humus layer of the soil.

The percentages of cobalt, nickel, molybdenum, and zinc show a distribution similar to that of iron but in a much more striking fashion. None of these, with two exceptions, were detected in layers

2 to 4, whereas they were present in most samples of the humus layer in amounts, ranging from 0.0001 to 0.03 percent. This suggests, again, that Pisonia concentrates these elements in its humus, enriching the upper layers of the soil. It has been suggested that this concentration of minor elements in the humus layer results from digested fish deposited as guano. This is possible, but these elements would probably then show up, also, in the phosphate accumulation layer. The two exceptions noted above were in profiles 26 and 50 where in layer 2 there were, respectively, 0.03 and 0.02 percent of zinc, the 0.03 percent being higher than the amount in layer 1. The 0.02 percent is in one of two analyses of phosphate rock from the same profile, this particular sample being of nodules or fragments of layer 2 included in the raw humus layer. The one of layer 2 proper showed no zinc. Cobalt, molybdenum, and zinc were not detected in two samples of Pisonia leaves which were ashed and analyzed (nickel was not checked in these).

The percentages of copper, manganese, barium, boron, and chromium were all low, ranging from 0.01 to 0.00004 percent, but they were always detectible by spectrographic analysis. No systematic relationships are apparent.

Strontium content ranges from 0.02 to 0.4 percent and is conspicuously lower in the humus layer than in the lower layers in all but one profile.

Hydrogen ion concentration in the three types of profiles

Determinations of pH made in the laboratory on samples which had been dried and stored do not, of course, correspond very well with those made on fresh samples by rough field methods. The laboratory determinations of pH show a greater total range and, except for those of the Jemo soils, are generally higher than the field determinations.

Available figures for relatively unaltered sands are well above pH 9, but in the surface layers of the Shioya series this figure drops to about pH 8.5. The lower layers of this series have pH readings similar to those of the unaltered sands. In the Arno Atoll series, layer 1 has an average pH of 7.9, layer 2, an average pH of 8.6, and in the lower layers, again, the pH is above 9. In the Jemo series the pH of layer 1 is 4.5, layer 2 has a pH of 7.6, and layer 3 has a pH of 8.3. These figures indicate that the increase in acidity is roughly related to the increase in organic matter. Hydrogen ion concentrations of about pH 9 seem to accompany amounts of organic carbon in soils of less than 2 percent, a pH of 8 those with 2 to 4 percent of organic carbon, pH readings of 6 or 7 those with 4 to 6.5 percent organic carbon, and pH of 3.8 to 5.3 those with 20 to 35 percent organic carbon. These figures clearly show a marked relation between the accumulation of organic matter and leaching. The more acid soil solutions resulting from the accumulation of humus are more active in leaching both the calcium carbonate in the parent materials and the phosphate added later.

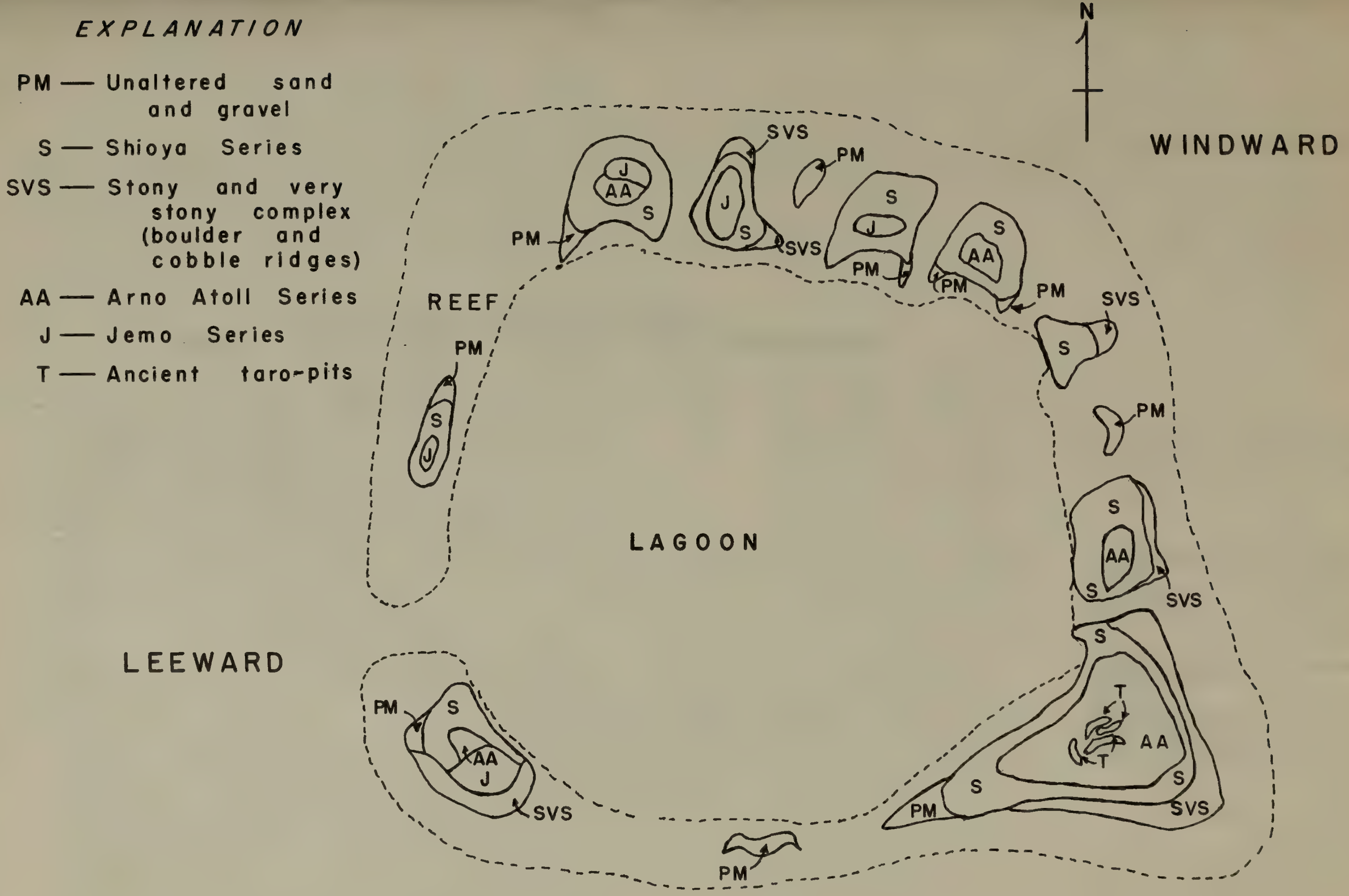
EXPLANATION
PM — Unaltered sand and gravel
S — Shioya Series
SVS — Stony and very stony complex (boulder and cobble ridges)
AA — Arno Atoll Series
J — Jemo Series
T — Ancient taro-pits
N
WINDWARD
LEEWARD
REEF
LAGOON
PM
S
SVS
AA
J
T

FIGURE 29. SCHEMATIC DIAGRAM OF A HYPOTHETICAL ATOLL SHOWING DISTRIBUTION OF SOIL TYPES

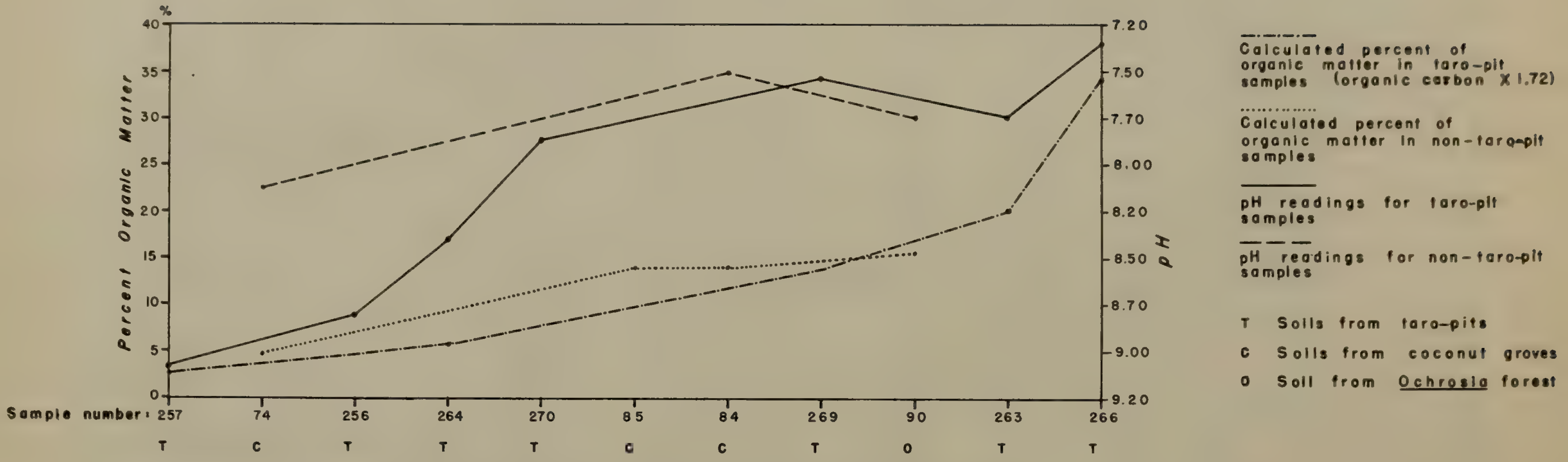

FIGURE 30. RELATION OF ACIDITY TO ORGANIC MATTER IN MISCELLANEOUS SOILS WITH HIGH ORGANIC MATTER CONTENT

Legends of plates

Plate 32. Effects of typhoon on Utirik islet.

A. Aerial view of western prolongation of Utirik islet, Utirik Atoll, swept clean of soil and vegetation by a typhoon many years ago, and again partially denuded in 1951. The boulder accumulation in the edge of the lagoon just below the dark line of vegetation was presumably swept from the land surface by the earlier typhoon. The faint darker lines in the right half of the land area are beachrock.

B. Closeup of an area in the left side of the area shown in A, being somewhat recolonized by vegetation. The coconut groves in the background were apparently protected by the broader parts of the islet from the severe effects shown in the narrow projection of the islet.

Photos by Fosberg.

Plate 33. Foraminifera in soils from the Marshall Islands. Examples of Foraminifera in various soils, showing changes due to organic matter and to removal of calcium carbonate.

A. Worn *Calcarina* from sample 131, profile 29, Shioya soil, Jemo island, showing slight adherence of organic matter (dark).

B. Corroded worn foraminifer from sample 48, profile 5, Arno Atoll soil, Utirik islet, Utirik Atoll.

C. Corroded foraminifer with broken chambers filled with organic matter, sample 204, profile 28, Jemo soil, Jemo island.

D. Foraminifer with dull, slightly earthy appearance, sample 48, profile 5, Arno Atoll soil, Utirik islet, Utirik Atoll.

E, F. Foraminifera with earthy appearance due to powdery calcium carbonate on the surface, sample 71, profile 30, Shioya soil, Jemo island.

G, H. Foraminifera with additional firm calcium carbonate deposited on the original surface, sample 146, profile 70, Arno Atoll soil, Wotho islet, Wotho Atoll.

I, J, K. Foraminifera coated with a mixture of flour-like calcium carbonate and fine-grained organic matter. I and K are from sample 204, profile 28, Jemo soil, Jemo island; J is from sample 110, profile A15, Shioya soil, Taka Atoll.

L, M. Worn and broken *Marginopora* showing intimate association with organic matter, sample 41, profile 2, Arno Atoll soil, Utirik islet, Utirik Atoll.

Photos by Starkey, U.S. Geological Survey, all X 30 (approx.).

A

B

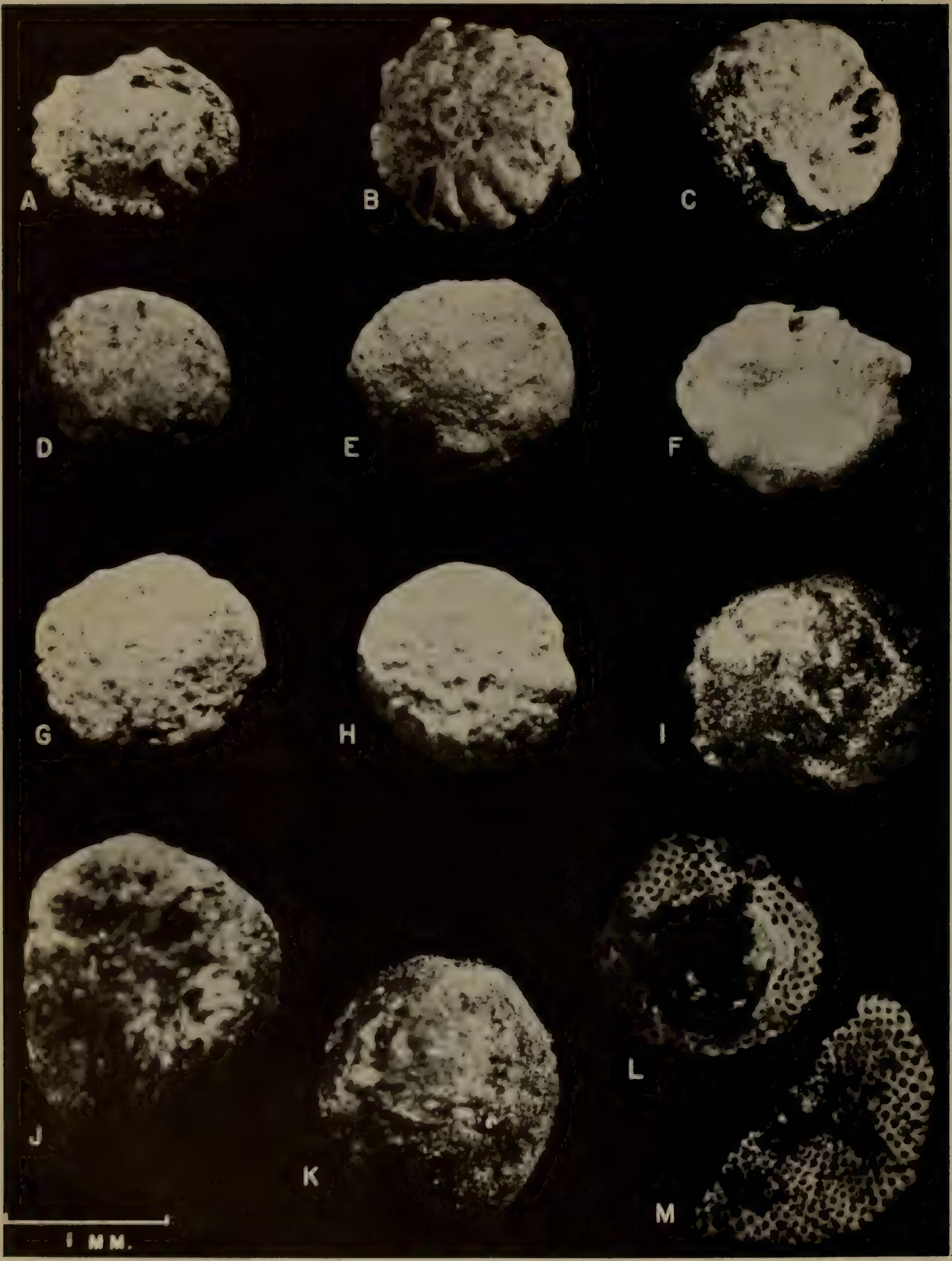
A
B
C
D
E
F
G
H
I
J
K
L
M
1 MM.

Table 9.--Major chemical constituents (in percent) and pH of northern Marshall Islands soils

Soil series or unit	Atoll	Profile No.	Layer No. (sample no.)	Depth (feet)	Organic carbon	Total N	Ca	Mg	Na	K	P	Total soluble salts[1]	NaCl in total soluble salts	pH
Unaltered sands	Ailuk	39	1 (252)	Surface	...	...	36.8	1.9	0.28	0.03	0.03	0.14	24.00	9.48
		40	1 (253)	do.	...	...	36.3	1.6	.31	.02	.03	.16	26.83	9.30
		Average for layer 1			...	...	36.6	1.8	.30	.03	.03	.15	25.42	9.39
Shioya series	Taka	11	1 (122)	0-0.8	...	...	...	...	...	...	...	.02	33.0	...
		12	1 (51)	0-0.9	...	...	...	...	...	...	...	.25	5.2	...
		13	1 (54)	0-0.25	...	...	...	...	...	...	...	.18	6.5	...
		A16	1 (116)	0-0.5	...	...	...	...	...	...	...	.04	24.5	...
	Likiep	17	1 (125)	0-0.6	...	...	36.2	1.3	.31	.03	.03	.12	25.5	8.97
			2 (126)	0.6-3.0	...	...	37.2	2.0	.31	.04	.02	.49	10.5	9.42
			3 (129)	3.0-6.0	...	...	35.6	2.7	.31	.03	.02	...	...	9.67
	Wotho	69	1 (141)	0-1.0	3.08	0.22	34.7	1.2	.26	.05	.20	.29	7.4	8.30
			1 (143)	0-1.0	1.58	...	37.5	.8	.27	.05	.21	.04	24.5	8.60
			2 (144)	1.0-3.0	...	...	37.8	1.4	.28	.03	.05	.12	60.94	...
		72	1 (148)	0-0.3	2.53	.22	33.7	1.1	.16	.03	.07	.09	33.0	8.06
			2 (149)	0.3-0.5	1.24	...	36.3	1.2	.18	.04	.03	.17	2.81	8.62
			3 (150)	0.5-1.8	...	...	37.3	1.7	.28	.03	.03	.24	1.21	...
		Average for layer 1			2.4	.22	35.5	1.09	.25	.04	.15	.17	20.0	[2]8.48
		do. 2			[3]1.24	...	37.1	1.60	.26	.04	.03	.27	24.22	9.02
		do. 3			...	...	36.5	2.20	.30	.03	.03	.16	[3]1.21	[3]9.67
Arno Atoll series	Utirik	1	1 (37)	0-0.7	6.01	.21	32.6	.49	.21	.03	2.0	.85	2.1	8.05
			2 (38)	0.7-1.1	3.20	...	35.5	.66	.21	.01	1.3	.50	3.0	8.16
			3 (39)	1.1-2.7	1.80	...	36.4	1.1	.21	.02	.52	.56	36.86	...
			4 (40)	2.7-4.0	...	...	37.2	1.8	.26	.02	.05	.56	55.82	...
		2	1 (41)	0-0.2	...	...	33.0	.90	.24	.02	.17	.24	15.6	8.30
			2 (42)	0.2-0.7	...	...	36.8	1.7	.30	.02	.06	.80	49.4	8.92
			3 (43)	0.7-1.8	1.25	...	36.9	1.8	.24	.02	.12	.12	6.08	8.87
			4 (44)	1.8-5.0	...	...	36.3	2.3	.30	.02	.03	.20	23.12	9.30
			4 (45)	1.8-5.0	...	...	36.0	2.3	.25	.02	.03	.28	15.72	...
		5	1 (47)	0-0.7	3.49	.13	34.6	1.1	.24	.02	.96	.50	4.6	7.98
			2 (48)	0.7-1.5	...	...	36.8	2.3	.30	.02	.08	.21	3.8	...
			3 (49)	1.5-2.5	...	...	36.2	2.5	.32	.02	.04	.24	4.64	...
			4 (50)	2.5-?	.24	...	36.3	2.4	.21	.02	.04	2.33	.07	9.20
	Ailuk	38	1 (77)	0-1.0	3.75	.17	35.0	.96	.23	.05	.34	.10	16.5	8.05
			3 (79)	1.8-2.7	...	...	36.1	1.8	.27	.05	.04	.36	33.5	...
			4 (81)	2.7-3.0	1.08	...	38.0	.58	.12	.05	.05	.06	19.3	8.52
	Jemo	27	1 (63)	0-0.7	11.0	.51	23.5	.39	.37	.05	9.9	1.15	72.8	7.30
			2 (64)	0.7-1.1	5.0	...	29.0	.49	.89	.05	8.5	1.75	88.3	7.57
			3 (66)	1.1-2.4	1.55	...	35.6	1.3	.37	.07	4.0	.53	73.5	7.85
			4 (67)	2.4-?	...	...	35.1	2.7	.36	.03	.31	.40	11.4	...
	Likiep	18	1 (58)	0-1.3	3.85	...	35.3	1.8	.24	.02	.14	.44	7.5	8.31
			2 (59)	1.3-2.5	...	...	35.9	2.0	.33	.02	.02	.16	16.73	8.80
			3 (60)	2.5-3.9+	...	...	36.1	2.8	.37	.02	.02	.08	29.97	9.47
	Ujelang	A3	1 (30)	0-1.5	4.1	...	...	...	...	...	...	...	...	...
	Lae	A11	1 (272)	0-0.6	...	...	...	...	...	...	...	...	...	8.11

Soil series or unit	Atoll	Profile No.	Layer No. (sample no.)	Depth (feet)	Organic carbon	Total N	Ca	Mg	Na	K	P	Total soluble salts[1]	NaCl in total soluble salts	pH
	Wotho	A9	1 (27)	0-1.0	3.4/	...	...	...	...	...	...	...	...	...
		70	1 (145)	0-1.0	2.88	.19	35.5	.84	.31	.03	.18	.03	33.0	8.35
			2 (146)	1.0-1.7	...	...	37.1	2.1	.21	.03	.05	...	...	...
		Average for layer[4]	1		4.04	.17	34.2	1.02	.25	.03	.63	.47	13.2	7.88
		do.	2		[3] 3.2	...	36.4	1.75	.27	.03	.30	.81	21.3	8.62
		do.	3		1.5	...	36.3	2.0	.28	.03	.15	.36	19.37	9.17
		do.	4		1.1	...	36.8	2.08	.23	.03	.04	.63	23.68	9.01
Jemo series	Bikar	153	1 (12)	[5] 0.15-0	31.44	2.53	7.6	.22	.27	.28	3.1	...	...	4.57
			2 (13)	0-0.1	...	...	34.5	.97	.33	.08	4.4	...	...	7.92
			3 (14)	0.1-1.2	...	...	36.2	1.7	.33	.06	.54	...	...	8.64
		165	1 (19)	[5] 0.7-0	30.87	1.95	9.0	.21	.34	.12	3.3	...	...	5.30
			2 (20)	0-0.5	...	...	34.8	1.1	.30	.06	5.2	...	...	8.07
		166	1 (15)	[5] 0.4-0	30.87	2.45	7.9	.22	.28	.17	3.4	...	...	4.80
			2 (16)	0-0.1	...	...	34.4	1.7	.30	.08	3.0	...	...	8.10
			2 (17)	0-0.1	...	...	34.0	1.3	.31	.07	5.0	...	...	7.60
			3 (18)	0.1-1.2	...	...	35.0	2.1	.31	.03	.56	...	...	8.57
	Taka	A14	1 (106)	0-0.9	...	...	...	...	...	...	...	0.11	11.9	...
	Jemo	25	1 (1)	[5] 0.5-0	19.92	1.64	16.5	.24	1.0	.06	6.8	2.10	78.0	5.17
			2 (2)	0-0.3	...	...	33.4	.48	.35	.05	7.7	...	...	7.71
			3 (3)	0.3-?	2.89	...	34.5	1.2	.61	.07	1.4	1.40	69.5	7.70
		26	1 (4)	[5] 1.0-0	34.26	2.15	3.9	.46	.89	.10	1.0	2.55	69.0	3.80
			2 (5)	0-?	5.33	...	31.3	.26	.51	.07	13.2	...	...	6.60
		32	2 (6)	Exposed	...	...	36.2	.78	.33	.04	6.0	...	...	8.31
	Kwaja-lein	49	1 (7)	Surface	34.71	2.83	2.5	...	.25	.08	.48	1.00	28.0	4.10
			2 (8)	0-?	...	...	35.8	.33	.42	.06	4.0	...	...	8.22
		50	1 (11)	Surface	26.73	2.10	10.9	.16	.33	.07	4.2	...	...	4.08
			2 (10)	do.	6.41	...	31.8	.08	.33	.07	13.4	...	...	6.30
			2[6] (9)	do.	3.11	...	32.8	.10	.36	.11	12.0	...	...	6.90
		Average for layer	1		29.8	2.24	8.3	.25	.48	.13	3.2	1.44	46.7	4.55
		do.	2		5.0	...	33.9	.71	.35	.07	7.4	...	...	7.57
		do.	3		[3] 2.9	...	35.2	1.66	.42	.05	.8	[3] 1.40	69.5	8.30

[1] Expressed as total weight of salts obtained by leaching with water.

[2] Empirical evidence indicates that when soils of different pH are mixed the resulting pH is close to an arithmetic average, even though this might not be expected from the expotential nature of pH numbers. It is felt, therefore, that the averages of the available pH determinations within layers and series may have some significance.

[3] Only one analysis.

[4] Profile 27 omitted from averages.

[5] Humus or A_0 layer is regarded as lying on the soil surface and depth is taken from the top of the mineral soil.

[6] Nodules from layer 2.

Table 9.--Major chemical constituents (in percent) and pH of northern Marshall Islands soils

Analysts, H. F. Phillips, K. E. White, P. L. D. Elmore, G. L. Otzelberger, and P. D. Blackmon

Table 10.--Occurrence of minor elements (in percent) in Jemo series soils

Analyst: Harry J. Rose. 0 in unit column indicates element below detection. All analyses were made on the ignited sample and corrected to the original sample weight.

Atoll	Profile No.	(Sample No.)	Cu	Mo	Zn	Mn	Co	Ni	Fe	Cr	Sr	Ba	B
Bikar	153	1 (12)	0.004	0	0	0.003	0	0.0002	0.03	0	0.03	0.0007	0.003
		2 (13)	.0004	0	0	.003	0	0	.005	.00009	.3	.001	.004
		3 (14)	.0002	0	0	.002	0	0	.002	.00008	.2	.0007	.002
	166	1 (15)	.004	.0008	.03	.003	.0003	.0004	.06	.00004	.06	.001	.002
		2 (16)	.0004	0	0	.003	0	0	.003	.00008	.2	.0009	.004
		2 (17)	.001	0	0	.004	0	0	.005	.00009	.3	.002	.005
		3 (18)	.0003	0	0	.003	0	0	.002	.0001	.1	.0005	.003
	165	1 (19)	.003	.0007	.01	.002	0	.0003	.03	.0001	.03	.0009	.002
		2 (20)	.001	0	0	.003	0	0	.003	.0001	.1	.001	.003
Jemo	25	1 (1)	.005	0	.03	.005	0	.0001	.07	.0002	.1	.002	.008
		2 (2)	.003	0	0	.003	0	0	.007	.0001	.1	.0009	.009
		3 (3)	.002	0	0	.003	0	0	.01	.0001	.3	.0009	.01
	26	1 (4)	.002	.0003	.004	.002	.0002	.0002	.04	.0001	.02	.0008	.004
		2 (5)	.003	0	.03	.006	0	0	.01	.0002	.1	.002	.01
	32	2 (6)	.0001	0	0	.005	0	0	.01	.0002	.2	.0009	.006
Kwajalein	49	1 (7)	.001	.0003	.007	.001	.0001	.0002	.02	.0001	.02	.0003	.004
		2 (8)	.002	0	0	.002	0	0	.007	.0002	.2	.0008	.009
	50	1 (11)	.005	.001	.03	.005	.0003	.0007	.2	.0006	.05	.0008	.001
		2 (10)	.002	0	0	.01	0	0	.02	.0005	.4	.002	.003
		2 (9)	.0009	0	0	.005	0	0	.008	.0003	.2	.002	.004
Averages for layers		1	.0031	.0004	.016	.003	.0001	.0003	.067	.00016	.04	.0009	.007
		2	.0015	0	.006	.004	0	0	.008	.00019	.21	.0014	.006
		3	.0008	0	0	.003	0	0	.005	.0009	.2	.0007	.005

Table 11.--Spectrographic determinations of minor elements in the Jemo series soils

Analysts: Helen Worthing and Katherine V. Hazel

Atoll	Profile No.	Layer No. (Sample No.)	0.X %	0.0X %	0.00X %	0.000X %
Bikar	153	1(12)		Fe, Sr	Cu, Mn, B	Ni, Cr, Ba
		2(13)	Sr		Mn, Fe, Ba, B	Cu, Cr
		3(14)	P, Sr		Mn, Fe, B	Cu, Cr, Ba
Bikar	166	1(15)	Sr	Zn, Fe, Sr	Cu, Mn, Ba, B	Mo, Co, Ni, Cr
		2(16)			Mn, Fe, B	Cu, Cr, Ba
		2(17)	Sr		Cu, Mn, Fe, Ba, B	Cr
		3(18)	Sr, P		Mn, Fe, B	Cu, Cr, Ba
Bikar	165	1(19)		Zn, Fe, Sr	Cu, Mn, B	Mo, Ni, Cr, Ba
		2(20)	Sr	Ba, B	Cu, Mn, Fe	Cr
Bikar	163	2(161)		Fe, Sr, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
Bikar	157	2(163)		Fe, Sr, B, Si	Cu, Cr, Ba, Al	Mn, V, Y, Ti
Bikar	164	2(165)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
Bikar	156	2(177)	Sr	B, Si	Cu, Fe, Cr, Ba, Al, V, Y	Mn, Ti
		3(180)	Sr	Fe, B, Si, Al	Cu, Cr	Mn, Ba, V, Ti
		3(181)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
		6(183)	Sr, Fe	Cu, Zn, B, Si, Al	Mn, Cr, Ba, V, Ti	Y, Ag
		6(184)	Sr	Cu, Fe, B, Si, Al	Zn, Mn, Cr, Ba	V, Ti
Bikar	177	2(229)	Sr	Zn, Fe, Si	Cu, Cr, Ba, B, Al	Mn, V
Bikar	156	6(227)	Sr	Si, Al, B, Fe	Zn, Cu, Ba, Cr, Ti, V	Mn
Bikar	158	2(159)		Sr, Si, Fe, B, Zn	Al, Cu, Ba, Cr, V	Mn, Ti
Bikar	174	3(169)		Sr, Fe, Si, Al, Zn	B, Cu, Cr	Ba, Mn, Ti, V
Bikar	176	2(172)	Si, Sr	Fe, Al, B	Cu, Ba, Cr	Mn, Ti, V
Bikar	178	2(173)		Si, Sr, Fe, Al, B	Ba, Cu, Cr	Mn, Ti, V
		2(174)	Sr	Fe, Si, Al, B	Cu, Ba, Cr, Mn	V, Ti
		2(175)	Sr	B, Fe, Si, Al	Ba, Cr, Cu	Mn, V

Table 11.--Spectrographic determinations of minor elements in the Jemo series soils--Continued

Atoll	Profile No.	Layer No. (Sample No.)	0.X %	0.0X %	0.00X %	0.000X %
Jemo	28	2(203)		Fe, Sr, B, Si, Al	Cu, Cr, Ba	Mn, V, Ti
Jemo	25	1(1)	Sr	Zn, Fe, Ba, B	Cu, Mn	Ni, Cr
		2(2)	Sr		Cu, Mn, Fe, B	Cr, Ba
		3(3)	Sr	Fe, B	Cu, Mn	Cr, Ba
Jemo	26	1(4)		Fe, Sr	Cu, Zn, Mn, B	Mo, Co, Ni, Cr, Ba
		2(5)	Sr	Zn, Fe, B	Cu, Mn, Ba	Cr
Jemo	32	2(6)	Mg, Na Sr	K, Fe	Cu, Mn, B	Cr, Ba
Ujae	110	2(191)	Sr	Fe, Si, Al	Cu, Cr, Ba, B, V, Ti	Zn
Ujae	73	2(211)	Sr	Fe, Si, Al	Cu, Cr, Ba, B, V, Y	Mn, Ti
Ujae	74	2(213)	Sr, Si	Fe, Al	Cu, Zn, Cr, Ba, B, V, Ti	Mn
Ujae	79	2(217)	Sr	Fe, B, Si, Al	Cu, Cr, Ba, V, Ti	Mn
Ujae	97	2(225)	Sr	Fe, B, Si, Al	Cu, Mn, Cr, Ba, Ti	V
Wotho	117	2(193)		Ni, Fe, Sr, Si	Cu, Cr, B, Al, V	Mn, Ba, Ti
Wotho	118	2(195)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, Y, Ti
Wotho	119	2?(189)	Sr	Si, B, Fe	Al, Ba, Cr, Cu, Ti, V	Mn
Kwajalein	49	1(7)	Na, P	Fe, Sr	Cu, Zn, Mn, B	Mo, Co, Ni, Cr, Ba
		2(8)	Mg, Na Sr	K	Cu, Mn, Fe, B	Cr, Ba
Kwajalein	50	1(11)	Mg, Na, Fe	K, Zn, Sr	Cu, Mo, Mn, B	Co, Ni, Cr, Ba
		2(10)	Na, Sr	Mg, K, Zn, Mn, Fe	Cu, Ba, B	Cr
		2(9)	Mg, Na, Sr, K		Mn, Fe, Ba, B	Cu, Cr

Table 12.--Ranges in amounts of minor elements in samples of soil materials from the Jemo soil series on Bikar, Jemo, Ujae, Kwajalein and Wotho Atolls.

For elements above double line, determinations were made on 45 samples; for those below lines, on 25 samples.

Element	Range (percent)	Frequently (number of times found)	Total
Boron	0.0X, 0.00X	23, 22	45
Barium	.0X, .00X, .000X	1, 28, 15	44
Cobalt	.000X	4	4
Chromium	.00X, .000X	17, 28	45
Copper	.0X, .00X, .000X	2, 5, 38	45
Iron	.X, .0X, .00X	2, 33, 10	45
Manganese	.0X, .00X, .000X	1, 23, 20	44
Molybdenum	.00X, .000X	1, 4	5
Nickel	.0X, .000X	1, 27	28
Strontium	.X, .0X	32, 13	45
Zinc	.0X, .00X, .000X	10, 5, 1	16
Aluminum	.0X, .00X	13, 9	22
Silicon	.X, .0X	1, 24	25
Silver	.000X	1	1
Titanium	.00X, .000X	5, 16	21
Vanadium	.00X, .000X	10, 14	24
Yttrium	.00X, .000X	2, 3	5

Table 13.--Organic carbon (percent) and pH of certain highly organic soils

Atoll	Profile	Layer No. (Sample No.)	Organic carbon (percent)	pH	Situation
Utirik	6	1 (256)	2.65	8.76	Taro pit.
		2 (257)	1.45	9.03	
Ailuk	A21	1 (263)	11.67	7.68	Taro pit.
		2 (264)	3.37	8.37	
Ujae	81	1 (84)	8.12	7.45	Surface soil on rubble in coconut grove where trash has decomposed for a long time.
	82	1 (85)	8.11	7.58	Bottom of depression in coconut grove.
	102	1 (90)	9.40	7.70	Thin surface layer in *Ochrosia* forest.
Lae	A7	1 (266)	19.86	7.30	Taro pit.
	A8	1 ([illegible])	8.17	7.52	Taro pit.
		2 ([illegible])	4.33	7.82	
	A10	1 (74)	2.59	8.09	Coconut grove.

Table 14.--Major chemical constituents (average percentages) and pH[1] of samples from Arno Atoll, Shioya, and Jemo series soils collected from atolls in the northern Marshall Islands

Soils	pH	Organic carbon (percent)	Calcium (percent	Magnesium (percent)	Phosphorus[2] (percent)	Sodium (percent)	Potassium (percent)	Soluble (percent)
UNALTERED SANDS								
(parent material)	9.39	...	36.6	1.8	0.03	0.30	0.03	0.15
SHIOYA SERIES								
Layer 1	8.48	2.4	35.5	1.09	.15	.25	.04	.17
Layer 2	9.02	[3]1.2	37.1	1.60	.03	.26	.04	.27
Layer 3	[3]9.67	...	36.5	2.20	.03	.30	.03	.16
ARNO ATOLL SERIES[4]								
Layer 1	7.88	4.04	34.2	1.02	.63	.25	.03	.47
Layer 2	8.62	[3]3.2	36.4	1.75	.30	.27	.03	.81
Layer 3	9.17	1.5	36.3	2.00	.15	.28	.03	.36
Layer 4	9.01	1.1	36.8	2.08	.04	.23	.03	.63
JEMO SERIES								
Layer 1	4.55	29.8	8.3	.25	3.2	.48	.13	1.44
Layer 2	7.57	5.0	33.9	.71	7.4	.35	.07	...
Layer 3	8.30	[3]2.9	35.2	1.66	.8	.42	.05	[3]1.40

[1] See explanation in footnote 2 on table 9.
[2] Averages of rapid chemical method determinations only.
[3] Single determination.
[4] Profile 27 omitted from averages.

SUMMARY AND CONCLUSIONS

This investigation has shown that the islets on the atoll reefs of the northern Marshall Islands are mainly accumulations of calcareous debris, generally formed around erosion remnants of former slightly higher reef platforms, more rarely without such stabilizing cores. Their surface features conform sufficiently to a few patterns that their descriptions may be generalized and consistent terms applied to their common features. On the basis of their origin and position three types of islets are recognized--outer reef islets of detritus accumulated around a solid erosion remnant of a higher platform; outer reef islets composed of detrital accumulations without such a core; and islets built of detritus within lagoons.

The calcareous materials are either freshly derived or reworked skeletons or fragments of skeletons of marine plants and animals, or fragments of consolidated masses of such skeletons, and are mineralogically mixtures of calcite and aragonite. Most of the calcite is a more or less magnesian calcite. The characteristics, both physical and chemical, of the sediments are determined in large measure by the organisms of which they are principally composed. These characteristics, especially the physical ones, are modified both by the amount of weathering and abrasion they have been subjected to and by their position on the islet, either as constantly moving beach materials or as relatively stable deposits within the islets.

The interior deposits, considered as soils, are mostly referable to three previously recognized soil series, of which the Shioya and Arno Atoll series are almost entirely calcareous, differing principally in the amount of organic matter in their upper layers or A horizons. The Jemo series is highly phosphatic, with a raw humus A_0 horizon and a consolidated B horizon of phosphate rock. Chemically the Shioya soils are deficient in almost every plant nutrient element except calcium. The Arno Atoll series is more suitable for plant growth but is deficient in most elements. The Jemo soil has an abundance of phosphorus and has, in its A_0 horizon, more of most other essential elements than is general in atoll soils, though the quantities are even so extraordinarily small. The distribution of various elements through the profiles shows certain systematic trends. Interpretation of these is difficult at present and in most respects must await further data. Deficiencies of most nutrient cations, including some of the essential trace elements, are evident in all the soils studied. The ability of certain species of plants to grow in spite of these deficiencies, and the complete failure of others, is noteworthy. The process of phosphatization and hardpan formation in the Jemo series is fairly well understood, being dependent on the coincidence of guano from seabirds and acid humus from Pisonia trees. The chemistry and ecology of the formation of the Arno Atoll series is not well understood.

Further research should perhaps take the form of detailed mapping of the occurrence of the several soil types on selected islets in atolls with different climates and where as much as possible of the original vegetation remains. Correlation with vegetation patterns should be attempted. Further and more detailed chemical studies might profitably be made on selected profiles in the several series. An attempt should be made to find the origin of the indicated trends in occurrence of minor elements and to determine the fertility relations of the soils as substrata for plant growth. Attention should also be paid to the weathering processes going on in these sediments under different climatic conditions. The role of microscopic blue-green algae both in weathering and nitrogen fixation should be determined, as well as their contribution to the accumulation of organic matter. Finally, as investigation to determine relative and absolute ages of layers in the sections would be of great interest in relation to soil formation, climatic history and sea-level changes.

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APPENDIX I

Data for beach sand samples collected by
Charles G. Johnson and F. Stearns MacNeil

1. Samples collected by Charles G. Johnson

Taongi (Pokak) Atoll (fig. 5)

T-1. Sand from small pit in reef 25 feet south of passage, on lagoon side. Pit about 3 inches deep, sand on bottom about 3 inches deep.

T-4. Beach sand from about mean tide level on the lagoon side near the middle of Sibylla islet.

T-5. Beach sand from the windward side and south of the middle of Sibylla islet. Sample was taken well above high-tide level.

T-6. Beach sand from above high-tide level on the windward side and north end of Sibylla islet.

T-7. Beach sand from the east end of the pass at the north end of Sibylla islet.

T-8. Beach sand from the windward side and north end of Bwdije (Breje) islet.

T-9. Beach sand from the lagoon side and north end of Bwdije (Breje) islet.

T-10. Beach sand from the windward side and south end of Kamwome islet. Sample from above high-tide level.

T-11. Beach sand from lagoon side and south end of Kamwome islet.

T-12. Beach sand from the head of a small reentrant on the lagoon side of Kamwome islet.

T-13. Beach sand at the mouth of the north side of a small reentrant on the lagoon side of Kamwome islet. This reentrant is the same as that of T-12.

T-14. Beach sand from the lagoon side and north end of Kamwome islet.

T-15. Beach sand from the windward side and north end of Kamwome islet.

T-16. Beach sand from the windward side of North islet.

T-17. Beach sand from the lagoon side of North islet.

T-19. Beach sand from the windward side and near the middle of Kamwome islet.

T-20. Beach sand from the lagoon side on south end of Sibylla islet.

T-21. Beach sand from the seaward side on south end of Sibylla islet.

T-22. Beach sand from the lagoon side and south end of an unnamed island north of Pokak islet.

T-23. Sand from the middle of a channel halfway between an unnamed island and Pokak islet.

T-24. Beach sand from the lagoon side and near the north end of Pokak islet.

T-25. Beach sand from the seaward side and near the south end of Pokak islet.

T-26. Beach sand from the seaward side and near the middle of Pokak islet.

T-27. Fine sand from the lagoon about 100 feet offshore of Pokak islet.

T-28. Sand from a pit in a small lagoonal reef on the windward side of atoll. Triangulation Station No. 5 is located on this reef. This sample was taken by one of the boatmen.

T-29. Beach sand from the seaward side and northeast end of Bwokwla islet.

T-30. Beach sand from the seaward side and southwest end of Bwokwla islet.

T-31. Sand from a pit in a small reef on the leeward side and south end of atoll. This sample smelled of hydrogen sulfide. Triangulation Station No. 12 is located on this reef.

T-32. Beach sand from the windward side and near the middle of Sibylla islet.

T-33. Sand from a small pit in a lagoonal reef on the windward side and north end of atoll. Triangulation Station No. 9 is located on this reef.

T-34. Sand from a small pit in a lagoon reef on the edge of the windward reef in the northern part of atoll. Triangulation Station No. 7 is located on this reef.

Bikar Atoll (fig. 6)

B-1	Sand bar at Survey Station No. 4, northeast part of lagoon.
B-3	Sand at north end, east side of Bikar islet.
B-4	Sand at middle of east side of Bikar islet.
B-5	Sand at south end, east side of Bikar islet.
B-6	Sand at south end, west side of Bikar islet.
B-7	Sand at middle of west side of Bikar islet.
B-8	Sand at north end, west side, Bikar islet.
B-9	Sand from leeward reef on north side of passage into lagoon.
B-10	Sand bar on northwest corner of atoll.
B-11	Sand from lagoon side of Almani (Alemeni) islet.
B-11	Sand from windward (southeast) side of Almani (Alemeni) islet.
B-13	Sand bar on lagoon side south of Jabwelo (Jalliklik) islet.
B-14	Sand from hole in bored platform, windward side, north of Jabwelo (Jalliklik) islet.
B-15	Sand from north end, windward side, Jabwelo (Jalliklik) islet.
B-16	Sand from reef side of Jaboero islet.

2. Samples collected by F. Stearns MacNeil

Locality (figs. 7-15)

Number

1. Lagoon beach of elongate western extension of Utirik islet, Utirik Atoll.
2. Tidal swirl pool along inter-island passage near north tip of Utirik islet.
3. Sand horn at north lagoon corner of Utirik islet.
4. High on beach at north tip of Utirik islet.
5. Beach sand near northwest corner of Taka islet, Taka Atoll, on inter-island passage side.
6. Seaward windward beach, Ailuk islet, Ailuk Atoll.
7. Seaward beach at west corner of peninsula off northeastern side of Emejiwan islet, Likiep Atoll.
8. Beach at northwest corner of Emejiwan islet, Likiep Atoll.
9. Seaward beach of Torrutj islet, Kwajalein Atoll.
10. Lagoon beach of Torrutj islet, Kwajalein Atoll.
11. Lagoon beach, Ninni islet, Kwajalein Atoll. About mid-point of lagoon beach.
12. Western tip of Eniwetak islet, Kwajalein Atoll.
13. Lagoon beach, Bokerok islet, Ujae Atoll.
14. Northeast corner of Enejalto islet, Lae Atoll, seaward side.
15. Seaward beach of northwest prong of Wotho islet, Wotho Atoll, just west of dry sand passage separating Wotho and Enerikon islets.
16. Beach at head of large cove on north side of Wotho islet, Wotho Atoll.
17. Lagoon beach, Wotho islet.
18. Seaward beach near south end of Wotho islet.
19. Lagoon beach near northwest of Eirek islet, Wotho Atoll.
20. Top of dune behind lagoon beach of Eirek islet, Wotho Atoll.

Number	Locality, continued
21.	Lagoon beach near southeast end of Eirok islet, Wotho Atoll.
22.	Bottom sample at end of lobe extending into lagoon at west end of Raej islet, Ujelang Atoll.
23.	Sand accumulation at lagoon side of what is either an indurated rubble flat or the remnant of a raised reef flat near east end of Ujelang Atoll.
24.	Lagoon beach of Nelle islet, Ujelang Atoll.
25.	Sand from irregularities on raised rock platform on seaward side of Maronlik islet, Ujelang Atoll.
26.	Beach along west side of Maronlik islet, Ujelang Atoll.
28.	Rock platform at north seaward corner of Taka islet, Taka Atoll.
J-1	Lagoon beach, Torrutj islet, Kwajalein Atoll.
J-2	Lagoon beach, Ninni islet, Kwajalein Atoll.
J-3	Beach sand northwest side Taka islet, passage side.
J-4	Beach, west side of point 8, Ujelang islet, Ujelang Atoll.
J-5	Sand on seaward rock platform, point 8, Ujelang islet.
J-6	Beach sand Bokerok islet, Ujae Atoll.
J-7	Beach, Eniwetak islet, Kwajalein Atoll.
J-8	Beach sand northwest corner Emijewan islet, Likiep Atoll.
J-9	Sand on seaward rock platform, point 8, Ujelang islet.
J-10	Seaward beach Torrutj islet, Kwajalein Atoll.
J-11	Northeast corner Enemanit islet, Lae Atoll.
TW-4	Taka No. 3 dug hole
U-5	Utirik islet, out on spit.

Description of samples 1 to 23:

Sample 1

Lagoon beach of elongate western extension of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from lagoon beach of narrow western extension, about 2 miles from eastern end, on the southern reef, extending nearly E-W, lagoon beach facing north.

Other data: The western tip of the islet was denuded by a typhoon years ago and the unconsolidated materials washed into the lagoon. The present high-beach ridge on the lagoon side probably represents repiling of some of the finer material.

Character:	Size (mesh[*/])	Percent	
	3	0)	coarse
	4	1)	
	9	6)	
	14	15)	medium
	35	75)	
	less than 35	3	fine

[*/] Sieve openings: 3, 6.35 mm; 4, 4.76 mm; 9, 2.00 mm; 14, 1.19 mm; 35, 0.42 mm.

Fragments moderately to much worn with an occasional sharp fragment. Larger pieces (4 and 9 mesh) are whole shells of mollusks, pieces of coral and coralline algae, and orbitoids. Most orbitoids seem less worn than do other constituents. Two smaller screens (14 and 35 mesh) held about half worn fragments of corals and algae and about half worn Baculogypsina and Calcarina and a few scattered orbitoids, and echinoderm and mollusk fragments. Material passing through 35-mesh screen more angular than larger sizes, consisting of fragments of algae, corals, Foraminifera, mollusks, echinoids, etc., some fresh small Foraminifera and embryonic gastropods and calcareous spicules.

Remarks: Freshness of orbitoids, mollusks, and some smaller Foraminifera indicates recent addition. Calcareous crusts on many coral and algae fragments similar to that on material from dug holes suggests much of material was derived from unconsolidated island sediments by typhoon mentioned above.

Sample 2

Tidal swirl pool along inter-island passage near north tip of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from ripple-marked (high) tidal swirl pool along edge of inter-island spillway a few feet behind sand horn at lagoon corner. Reef at this point trends about NW-SE. Spillway develops behind several disconnected remnants of an indurated rubble track. Beach behind swirl pool faces NNE. Point about 1 mile from east end of island.

Other Data: Material in swirl pool is agitated at each tide with a general movement toward the sand horn. Probably much of material worked lagoonward along beach.

Character:	Size (mesh)	Percent	
	3	0.5)	coarse
	4	.5)	
	9	2)	
	14	2)	medium
	35	25)	
	less than 35	70	fine*/

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*/ Fine fraction was resieved to conform to the Wentworth Scale

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Larger fragments, mainly coral and algal, moderately to well worn, shells worn to fresh. Medium particles about half Foraminifera and half coral and algal and other fragments, worn to angular; spiny Foraminifera with most of spines partly or wholly broken off but with discs little worn, smaller Foraminifera and most orbitoids little worn or fresh. Finer particles slightly worn to angular, consisting of a few very small Foraminifera, embryonic gastropods, calcareous spicules, and fragments of other Foraminifera, corals, algae, etc.

Remarks: No evidence of calcareous crusting. All materials apparently freshly derived, much of it having moved lagoonward along sides of passage from seaward beaches. A large percentage of mollusks and orbitoids and some other forams recently added.

Sample 3

Sand horn at north lagoon corner of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from about halfway out on long low horn exposed only at low tide. Horn about 1 mile from windward (E) end of island. Sample from 150 to 200 feet out on horn. Horn oriented about W by N.

Other data: The present horn is more elongate and located more in line with the passage beach than with the more prominently bent horn on the 1944 photos which is oriented with the lagoon beach, curving lagoonward towards the end.

Character:	Size (mesh)	Percent	
	3	30)	coarse
	4	4)	
	9	15)	
	14	15)	medium
	35	35)	
	less than 35	1	fine

The larger fragments, mainly corals, algae and mollusca are moderately to well worn. The medium-sized particles, about 60 percent forams and 40 percent other, are worn to angular, the spiny Foraminifera with spines mostly broken off but discs not worn, and the orbitoids and small mollusk shells not perceptibly worn. The fine fragments are mostly sharp and angular, consisting of fragments of Foraminifera, corals, algae, etc., with some calcareous spicules.

Remarks: Presumably the fines are winnowed out rapidly here, and carried into the lagoon. At the same time there is a larger amount of coarse- to gravel-sized material accumulating.

Sample 4

High on beach at north tip of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from highest part of beach at extreme north corner. Located about 1 mile from seaward (E) end of island.

Other data: Coarse material piled at top of beach to a depth of about 2 inches. Beneath it is a layer of medium fine to fine sand of undetermined thickness. Only a few scattered medium to coarse fragments in fine sand.

Character:

	Size (mesh)	Percent
surface layer - all more than 3		
substratum:	4	Trace
	9	Trace
	14	Trace
	35	20
less than	35	80

Material of surface layer consists mainly of worn coral fragments as much as 1 1/2 inches in longest dimension with a few pieces of coralline algae and mollusk shells.

Material of substratum consists mainly of angular fragments of corals, algae, Foraminifera, and mollusks with occasional whole specimens of smaller Foraminifera, embryonic gastropods and calcareous spicules.

Remarks: The nearly complete absence of intermediate-sized particles suggests entirely different causes for the deposition of the two layers. The lower fine zone is similar to fine material in the tidal swirl nearby, although which was derived from the other is difficult to say. The coarse upper zone is probably a high wave cast zone, probably with the fines winnowed out and perhaps settling out.

Sample 5

Beach sand near northwest corner of Taka islet on inter-island passage side.

Atoll position: Islet at southeast side of atoll. Reef to north of islet trends N-S, and to south of islet trends about NE-SW. Beach where sample was taken is between 0.2 and 0.3 mile from seaward edge and faces about due north or N. by E.

Other Data: A great many echinoid tests were strewn along the beach.

Character:

	Size (mesh)	Percent	
	3	Trace	
	4	0.5)	coarse
	9	8)	
	14	35)	medium
	35	55)	
less than	35	1.5	fine

Larger fragments moderately worn with a few fresh angular fragments, and a few fresh mollusk shells, consisting of fragments of corals, algae, echinoids, mollusks and some orbitoids. Medium-sized particles more angular, contains about 40 percent spined forams with spines mostly broken off but discs not worn, and about 60 percent coral, algal, mollusk, and other fragments and numerous fresh orbitoids and small gastropod shells. Fine particles angular or with only one side rounded, indicating breaking from larger rounded particles--consisting of fragments of coral, algae, mollusk shells, Foraminifera, etc.

Sample 6

Seaward windward beach, Ailuk islet.

Atoll position: Islet located at southeast corner of atoll. Sample from seaward beach at about center of eastward-facing stretch. Windward reef trends approximately N-S. South-facing reef trends nearly E-W. Beach 100 yards from reef edge.

Other data: The sand forms crescent-shaped beaches between projections of beach rock and raised reef rock. The materials are washed directly toward the beach from the reef flat and marginal zone, much of it being moved across the reef from one minor irregularity or depression to the next and finally to the beach.

Character:	Size (mesh)	Percent	
	3	20)	course
	4	6)	
	9	50)	
	14	20)	medium
	35	3)	
less than	35	1	fine

Most materials fresh, angular and unworn, although occasional pieces are well rounded. Coarser sizes made up of corals, algae, mollusks, echinoid spines and plates and orbitoids with a small percentage of crustacean fragments. Medium-sized material more than half spiny forams and orbitoids, the remainder algae and other fragments. Only occasional coral fragments are present. Fine material consisting of fragments of algae, corals (?), Foraminifera, calcareous spicules and numerous transparent fibers not seen in more worn sands.

Remarks: All of this material is very little worn and close to its source. Most coral fragments are large, very little having been broken down. The fine material consists of a high percentage of originally small organisms or small structures of organisms. Many of the gastropods have well-preserved protoconchs.

Sample 7

Seaward beach at west corner of peninsula off northeastern side of Emejiwan islet, Likiep.

Atoll position: Innermost of two islets located on lagoonless projection of reef at northwest end of atoll. Samples from seaward (windward) beach at end of wedge-shaped peninsula and situated behind a tract of raised reef. Beach faces nearly north and is about 150 yards from reef edge.

Other data: The beach is worked by waves only at high high tides and during storms. Ordinary tides do not cover the raised reef platform.

Character:	Size (mesh)	Percent	
	3	0)	
	4	Tr)	coarse
	9	25)	
	14	23)	medium
	35	50)	
less than	35	2	fine

Larger sizes consist of moderately to well-worn fragments of calcareous algae, corals, hydrocorallines, echinoids and mollusks. Medium-sized particles include worn pieces of coralline algae and less worn segments of Halimeda, together with less worn to fresh orbitoids, spiny and other Foraminifera and small mollusks. There is also a scattering of worm tubes and fragments of precious coral. Fragments of anthozoan corals are a minor constituent. The fine material consists of little worn fragments of all the above plus a larger amount of small Foraminifera and some calcareous spicules. Moderately abundant shreds of plant material are included. Some very fine (-100 mesh ?) material is included.

Remarks: Much of this material is freshly derived as shown by good preservation of spines on Foraminifera and the excellent preservation of orbitoids and some mollusks. Other algal and coralline fragments are much worn and presumably have been on the beach for a considerable period. The possibility of two histogram peaks, one for worn and one for fresh material is suggested. It is possible that some material is secondarily reworked from unconsolidated sand deposits which once covered the raised flats. Pockets of sand on the raised flat show the step-by-step movement of new materials beachward.

Sample 8

Beach at northwest corner of Emejiwan islet, Likiep.

Atoll position: Islet is the innermost of two located on a projection of the reef beyond the end of the lagoon. The northwestern tip of the island is in line with the leeward beach (there being no lagoon here), and about 100 yds. from the windward reef edge.

Other data: All sediment trains and erosional features indicate movement of sand across the reef flat from the windward edge and windward beaches to the leeward beaches and leeward reef flats.

Character:	Size (mesh)	Percent	
	3	0)	coarse
	4	Tr)	
	9	10)	
	14	40)	medium
	35	50)	
	less than 35	Tr.	fine

The materials are nearly identical in preservation and composition to those of sample 7, the main difference being the concentration of medium-sized particles.

Remarks: This material is obviously derived from the windward side. The nearly identical preservation suggests quick trans-reef movement by tidal currents. The preservation of materials here should be comparable to that at the lagoon corners of islands bordering the lagoon, the leeward beach here corresponding to lagoon beaches elsewhere.

Sample 9

Seaward beach of Torrutj islet, Kwajalein.

Atoll position: Islet located on leeward side of southern projection of atoll. Reef at this point trends nearly N-S.

Other data: The lagoon is more than 20 miles wide at this place, curving and becoming wider to the north. There is no reef alined in a windward direction along which sands could be moved by waves. The leeward reef bends far to the west above this point, and the southern tip of the atoll lies about 25 miles to the southeast.

Character:

Size (mesh)	Percent	
3	0.5)	coarse
4	.5)	
9	35)	
14	3)	medium
35	60)	
less than 35	1	fine

Grains well worn with somewhat more angular particles among the fine and medium sizes. Coarser particles are predominantly coral and coralline algae with minor amounts of molluscan fragments. The coarse medium size contains about 30 percent coral and coralline algae fragments, and about 20 percent highly worn Foraminifera, whereas in the finer medium size worn and polished Foraminifera made up about 50 percent of the particles. The fine material consists of rounded to angular fragments of corals, coralline algae and forams, and an occasional fresh small foram. A few calcareous spicules are present, but they are much worn.

Remarks: There is a rarity of orbitoids and orbitoidal fragments in the sample which seems unusual if the material came originally from the windward reefs. However, there is an abundance of coralline algae which is rare on the leeward reefs, but a major constituent of the windward reef on both the growing edge and the detrital sediments. Spiny forams which flourish on the windward reef flat, and form a major part of the sands are highly worn and polished, and not a single specimen having spines was found. The discs are worn and polished, many or most of the pimples being worn off. The evidence is strong that most of the materials originated on the windward reefs.

Sample 10

Lagoon beach of Torrutj islet, Kwajalein.

Atoll position: Islet located leeward side of southern projection of atoll. Reef at this point trends nearly N-S.

Other data: See sample 9. Sand on the lagoon beach has been piled steeply, exposing layers of gentler dips with incipient lithification.

Character:

Size (mesh)	Percent	
3	0)	coarse
4	0)	
9	Tr.)	
14	1)	medium
35	97)	
less than 35	2	fine

Most of the particles are worn and polished with only an occasional freshly broken particle or unworn form. Scattered coarse particles are coral or algal fragments (Porolithon) and aggregates of poorly consolidated medium grains, probably broken-up beach rock. Medium textured material consists of worn forams (Calcarina, Amphistegina, and Marginopora) and about an equal amount of coral and algal (Porolithon) fragments, and scattered specks of red encrusting forams (Homotrema, etc.,), shell and echinoid fragments. The fines consist of finer fragments of the above with a few worn calcareous spicules and embryonic gastropods.

Remarks: The highly worn state of most materials suggests that the rate of addition of products of the leeward reef is very slow. A scattering of fresh specimens of Amphistegina, a species living in the lagoon, together with abundant worn Calcarina, and Marginopora and Porolithon fragments, which are added to lagoon sediments in abundance from the windward reef, suggests that a good part of the leeward sands are reworked lagoon sediments.

Sample 11

Lagoon beach Ninni islet, Kwajalein. About mid-point of lagoon beach.

Atoll position: Islet located on leeward side of southern arm of atoll. Reef at this point trends nearly NW-SE.

Other data: Fine, medium, and coarse zones are sharply separated on the beach--mixed evenly to form this composite sample.

Character: Sample mixed by hand to contain supposedly equal parts of fine, medium, and coarse zones; divided by screening into:

Size (mesh)	Percent	
3	10)	coarse
4	10)	
9	10)	
14	5)	medium
35	25)	
less than 35	40	fine*/

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*/ Fines were sieved to conform to the Wentworth Scale.

Coarse material consists of worn and polished pieces of corals, algae (Porolithon), mollusks, and a few echinoid spines and crustacean fragments. The medium-textured material consists of smaller, frequently more angular pieces of the above, and in addition moderately to highly worn and polished forams (Calcarina and Amphistegina) and a few specimens of each that are less worn, fragments of Marginopora and numerous ruby specks of encrusting forams (Homotrema). A few scattered worn Heterostegina are also present. The fines contain somewhat more angular fragments of all the above but with a surprisingly small percentage of foraminiferal fragments.

Remarks: Here again is a surprisingly large amount of algal material (Porolithon) suggesting that the windward reef was the main source of the material.

Sample 12

Western tip of Eniwetak islet, Kwajalein.

Atoll position: The islet, which is about a quarter of a mile long, lies within the lagoon, about one mile inside a passage near the midpoint of the eastern side of the atoll. The reef bends in towards the passage at this point, trending away from the passage in northeasterly and southeasterly directions.

Other data: The reef around the island has mainly coral growing on it. The northeastern shore is a coarse boulder beach composed entirely of boulders of beachrock--no coral heads as on the seaward boulder ramparts.

Character:	Size (mesh)	Percent	
	3	0)	coarse
	4	Tr.)	
	9	Tr.)	
	14	Tr.)	medium
	35	30)	
	less than 35	70	fine*/

The material is mostly fine medium to fine. Particles are worn and polished and consist mainly of corals, algae (Porolithon) and mollusks. The fine-medium-sized fraction consists of about 30 to 40 percent worn forams, mainly Calcarina and with lesser amounts of Amphistegina and broken Marginopora. The finer material consists of slightly more angular fragments of the above. Many ruby-colored specks of Homotrema are present in both fine and fine medium sizes.

Remarks: The materials here are worn and polished like the sands of the leeward reef. There seemed to be no evidence of any foram-laden algal mats on the narrow reef flat of the island, and presumably the forams were derived mostly from the windward reef of the atoll. There are also no growths of coralline algae along the island reef, suggesting that these too came from the windward reef, presumably via the lagoon. The nearly equal amounts of wear and polish on the coral and other fragments make it likely that all materials have had a more or less common origin and mode of transportation. Although this island is close to the windward reef its sands are more like the sands of the leeward beaches than the windward beaches, either on the seaward or lagoon sides. The similarity of the sands strongly suggest that they were derived from the lagoon.

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*/ Fines were sieved to conform to the Wentworth Scale.

Sample 13

Lagoon beach, Bokerok islet, Ujae Atoll.

Atoll position: Islet located on southeast side of Bock Channel which is at about mid-point of the leeward side of the atoll. The reef trends about NW-SE at this point.

Other data: Numerous coral knolls and reefs occur in the lagoon inside the channel. The sandy beach was developed only on the lagoon side and for a few feet around the sides of the island where it terminated steeply and abruptly. The remainder of the island beach is coarse rubble and bare raised reef rock.

Character:	Size (mesh)	Percent	
	3	Tr.)	coarse
	4	Tr.)	
	9	1)	
	14	5)	medium
	35	84)	
	less than 35	10	fine

The coarse screen retained only some fresh gastropod shells and some fragments of a poorly consolidated beach rock. The other coarse sizes were composed of rounded to angular pieces of coral, coralline algae (Porolithon), poorly consolidated beach rock, and 20 to 30 percent of Halimeda fragments, mostly broken. The medium sizes consist of worn to angular fragments of the same materials and in addition fragments of Marginopora, echinoid spines, mollusks, and medium to much worn specimens of Calcarina and Amphistegina. Scattered fragments of red Homotrema are also present. The Foraminifera make up only about 20 to 25 percent of the medium sizes. The fine material is made up of worn to subangular fragments of all the above.

Remarks: This sand is somewhat more angular than some other sands on the leeward islands. This may indicate that some was derived from the nearby knolls, or that it has not been on the beach for a very long period--the latter possibility may be supported by the rather restricted distribution of the sand on the island. The abundance of Halimeda fragments suggests here again that the sand was obtained from the lagoon sediments.

Sample 14

Northeast corner of Enejalto islet, Lae. Seaward side.

Atoll position: Islet located about one-fourth the distance from Lae islet on windward (northeast-facing) reef, the reef trending about NW-SE. The sample came from a broad seaward-facing horn on the seaward corner of the islet.

Other data: This unusual horn is apparently due to a short stretch of lagoonward-dipping beachrock on the seaward side of the island.

Character:	Size (mesh)	Percent	
	3	15)	
	4	10)	coarse
	9	30)	
	14	35)	medium
	35	10)	
	less than 35	Tr.	fine

The coarser material consists of unworn to moderately worn mollusk shells, and fragments of corals, coralline algae (Porolithon), hydrocorallines, echinoid spines, etc. The finer size (9 mesh) contains numerous well-preserved gastropods, Marginopora and Halimeda segments. The medium-sized material contains 60 to 70 percent well-preserved Calcarina, about 20 percent mixed Marginopora, small mollusks, and Homotrema fragments, and the remainder mixed fragments of coral, algae, echinoids, crustacea, etc. Numerous Volunlina occur in the 35-mesh sample. The fine material contains broken fragments of materials in the coarser sizes, and some shreds and filaments of broken up non-calcareous algae.

Remarks: This material, as might be expected, is close to the source of clastics, and relatively unworn. The rather large amount of Halimeda segments is unusual for a windward reef, but it was observed at other places that the outer moat locally supports prolific Halimeda colonies. The possibility that some Halimeda might have been derived from the lagoon by storm waves is suggested by the seaward point of this horn-like bar and the apparent lack of sand at the lagoon corner of the island--as if it had been washed seaward. This is contradicted by the virtual absence of highly worn Foraminifera which might be expected in lagoon-derived sediments--unless, of course, they were derived from the comparatively fresh sand lobes along the edge of the lagoon reef.

Sample 15

Seaward beach of northwest prong of Wotho islet, just west of dry sand passage separating Wotho and Enerikon islets.

Atoll position: Islet located at northeast corner of atoll, the beach facing north or a little east where the sample was taken.

Other data: This beach is partly in the lee of Enerikon islet.

Character:	Size (mesh)	Percent	
	3	20)	coarse
	4	8)	
	9	30)	
	14	20)	medium
	35	20)	
	less than 35	2	fine

The larger sizes consist mainly of little-worn corals, coralline algae (*Porolithon*), hydrocorals, mollusks, worm tubes, and a few large forams (*Marginopora*) and *Halimeda*. There is also a generous red sprinkling of organ coral (*Tubipora*) fragments and *Homotrema*, both loose and encrusting other organisms. The medium sizes consist of fully 90 percent unworn Foraminifera, mainly *Calcarina* and *Marginopora* with scattered *Amphistegina* and *Heterostegina*. The remaining 10 percent is composed of small mollusks, bryozoan fragments, and fragments of materials in the coarser sizes. The 35-mesh screen held a slightly higher percentage of angular detrital material and fewer Foraminifera than the 14-mesh screen. Numerous *Volunlina* are present in the 35-mesh material. The fine material consists mainly of angular fragments of above materials and in addition a scattering of small Foraminifera (miliolids and cymbaloporids), fragments of needle-thick echinoid spines, calcareous spicules, etc.

Remarks: All materials appear virtually unworn, showing clearly their nearness to their source, but the little amount of beach erosion in their present position. The latter may be due in part to the semi-protection of Enerikon islet. Organ pipe coral is more abundant here than usual.

Sample 16

Beach at head of large cove on north side of Wotho islet.

Atoll position: Islet located at northeast corner of atoll. The cove opens along the north side of the island and the prevailing wind affects it obliquely.

Other data: Fine material is concentrated at the southwest corner of the cove, where this sample was taken. The sand becomes increasingly coarser towards the east end of the head of the cove. The cove head is filling in, and appears to be an incomplete stage in the building of one large island from two smaller ones. The area behind the cove is not underlain by a raised rock flat whereas the larger areas on either side are.

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	Tr.)	coarse
	9	2)	
	14	13)	medium
	35	70)	
	less than 35	15	fine

The coarser fragments consist of fresh to moderately worn coral, coralline algae (*Porolithon*), mollusks, echinoid spines, and *Marginopora* with attached and detached *Homotrema*. The medium sizes contain moderately worn fragments of the above and an abundance of *Marginopora*, *Calcarina*, and *Amphistegina*. Most of the forams are fairly fresh, but most of the spines are broken off the *Calcarina*. The fine material is composed of little worn fragments of the above plus small forams (miliolids and cymbaloporids), embryonic gastropods, fragments of needle-sized echinoid spines and calcareous spicules. A few pelagic Foraminifera are present (*Tretomphalus*).

Remarks: This material is on the whole quite fresh, but somewhat more beach worn than nearby sample 15.

Sample 17

Lagoon beach, Wotho islet.

Atoll position: Islet at northeast corner of atoll. The point at which the sample was taken lies directly opposite the large cove on the seaward side, and in line with a bare scour scar that extends nearly to the lagoon beach. The lagoon beach at this point is nearly in the full lee, trending nearly NW-SE.

Other data: Water pours across the island at this point during major storms, and some of the sand here may have been derived from the large seaward cove by being washed directly across rather than having washed around the corners of the island.

Character:	Size (mesh)	Percent	
	3	shells)	
	4	shells)	coarse
	9	shells + Tr.)	
	14	Tr.)	medium
	35	75)	
	less than 35	25	fine*/

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*/ Fines were sieved to conform to the Wentworth Scale.

Shells of a small, smooth-ribbed cardiid make up almost all of the coarser material. A few worn corals, coralline algae (Porolithon), Halimeda, and small gastropods make up about 20 percent of the 9-mesh screenings. The medium-sized material is mostly smaller than 14 mesh, the 14-mesh material being composed mainly of small Marginopora and coral and algal fragments, with a few fragments of Homotrema. The coarser medium-sized particles are about 10 percent coral and algal fragments, and about 30 percent moderately worn Calcarina, Amphistegina and small Marginopora, with a scattering of both fairly fresh and highly worn specimens. The fine siftings consist of unrecognizable moderately worn to angular fragments of corals, algae, Foraminifera, and some fresh miliolids and cymbaloporids, calcareous spicules, small echinoid spines, and red to pink fragments of Homotrema and organ pipe coral (Tubipora).

Remarks: This material is definitely more worn than the material on the seaward side (samples 15 and 16). The abundant cardiid, which lives in the lagoon suggests derivation of some of the sand from the lagoon beach, probably during summer storms.

Sample 18

Seaward beach near south end of Wotho islet.

Atoll position: Islet at northeast corner of atoll. Sample from southern end of long stretch of beach (about 200 ft N of the north end of the southernmost stretch of exposed rock platform). The beach and reef edge trend nearly N-S at this point.

Other data: (none given)

Character:	Size (mesh)	Percent	
	3	Tr)	
	4	5)	coarse
	9	85)	
	14	10)	
	35	Tr)	medium
	less than 35	0	fine

The coarse material is composed of well-worn and polished coral, coralline algae (Lithothamnion), mollusks, echinoid and Halimeda material with a scattering of less worn or fresh Marginopora. The medium-textured material is similar, but with a higher percentage of Marginopora on the 14-mesh screen, and on the 35-mesh screen a few comparatively fresh specimens of Calcarina. The 35-mesh material is mostly angular. No fine material is present.

Remarks: This material is very much worn and polished for the windward reef. The amount of wear is probably due to slow movement along the long stretch of beach, and possibly entrapment behind the rock platform at the end, resulting in long wear on the same beach. The fines seem to have completely escaped. Quite fresh *Calcarina* in the medium sizes indicates that fresh material is still being added, nevertheless.

Sample 19

Lagoon beach near northwest of Eirek islet, Wotho.

Atoll position: The islet is located on the leeward reef in the southwestern part of the atoll. The reef trends NW-SE at this point. The sample is from the intertidal zone near the west end of the lagoon beach.

Other data: A large dune ridge rises directly behind the beach.

Character:	Size (mesh)	Percent	
	3	Tr.)	coarse
	4	nil)	
	9	Tr.)	
	14	4)	medium
	35	95)	
	less than 35	1	fine

The scattered coarse pieces present are worn corals, coralline algae (*Porolithon*), *Halimeda*, mollusks, etc. The medium sizes contain smaller worn fragments of the same and worn forams, mostly *Calcarina*. The material on the 35-mesh screen consists of about 50 percent worn and polished *Calcarina* and scattered *Amphistegina*, some of which are fairly fresh. Occasional unworn but spineless *Calcarina* can be seen. The fine material is comparatively unworn and mostly angular, apparently recently broken. A few small forams are present.

Sample 20

Top of dune behind lagoon beach of Eirek islet, Wotho.

Atoll position: Same as sample 19. Dune located directly behind beach.

Other data: The dune is about 9 to 10 feet higher than the inner edge of the beach and is partly healed over with vegetation. Numerous trees grow along its sides and crest although there is no mat of grass or other small vegetation covering it.

Character:	Size (mesh)	Percent	
	3	0)	coarse
	4	0)	
	9	0)	
	14	0)	medium
	35	30)	
	less than 35	70	fine*/

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*/ Fines were sieved to conform to the Wentworth Scale.

No materials were held by the 14 mesh and coarser screens except a few pieces of carbonaceous material. The finer medium textured material consists of polished to dull, angular to highly worn fragments of corals, calcareous algae, mollusks, *Marginopora*, etc., and worn to moderately fresh smaller Foraminifera, mainly small specimens of *Calcarina* and *Amphistegina*. A minor amount of purplish to reddish material is present, some of which are echinoid spine fragments and *Homotrema* and some of which may be alcyonarian, either organ pipe coral (*Tubipora*) or precious coral (*Corallium*). The fine material consists of smaller fragments of the above, and occasional whole minute forams, probably miliolids or cymbaloporids.

Remarks: The low percentage of fine material in the beach sand and the concentration of fines in the dune suggests that the dune material was largely winnowed from the adjacent beach. Most of the material of the beach and dune is distributed between the fine-medium and fine sizes.

Sample 21

Lagoon beach near south end of Eirek islet, Wotho.

Atoll position: Same as samples 19 and 20. Sample from broad lagoon beach near eastern end of island.

Character:	Size (mesh)	Percent	
	3	Tr.)	coarse
	4	Tr.)	
	9	5)	
	14	40)	medium
	35	45)	
	less than 35	10	fine

Materials of coarse and medium sizes highly worn and polished. The coarse materials are fragments of coral and calcareous algae (mostly *Halimeda* with a few scattered fragments of *Porolithon*), and mollusk shells. The medium sizes contain similar materials with a scattering of highly worn Foraminifera (*Calcarina* and *Amphistegina*) on the 14-mesh screen, and 50 percent or more on the 35-mesh screen. A few *Amphistegina* appear to be quite fresh. There is also a scattering of purplish or reddish echinoid spine fragments, *Homotrema* or alcyonarians. The fine material is more angular and mostly unpolished, in contrast to the larger sizes. In addition to the constituents of the larger sizes, there are a few fresh small Foraminifera (miliolids and cymbaloporids) and some calcareous spicules.

Remarks: The materials here are coarser than at the west end of the beach. The abundant *Halimeda* indicates that much of the material is derived from the lagoon. The high degree of wear may indicate a rather long period of working on the leeward reef, and may in part reflect a long process of transportation from its ultimate place of origin along the windward reef. The finer sizes appear to have moved to the westward, and the finest to have been blown landward to form a dune.

Sample 22

Bottom sample at end of lobe extending into lagoon at west end of Raej islet, Ujelang.

Atoll position: Islet located on windward reef about 3 miles from east end of atoll. The reef at this point trends generally WNW-ESE.

Other data: Sample taken by dredging at a depth of about 25 feet at inner side of sand lobe on lagoon reef. The lobe is located just west of Raej islet, and projects lagoonward about 100 feet beyond the normal margin of the lagoon beach. The reef at this point is nearly half a mile wide.

Character:

Size (mesh)	Percent	
3	1)	coarse
4	1)	
9	10)	
14	35)	medium
35	50)	
less than 35	3	fine

The coarse sizes contain fragments of corals, coralline algae (*Porolithon*), *Halimeda*, *Marginopora* and mollusks. Few fragments show much sign of recent wear although some edges are well rounded. A crust of dead bryozoans, worms, *Homotrema*, and other organisms covers some fragments, and on some there is an irregular encrustation of white amorphous material. The medium-sized material consists largely of the tests of *Calcarina*, *Amphistegina*, and *Marginopora*, some of which are encrusted with a small amount of white amorphous material. The spines of the *Calcarina* are mostly broken, but otherwise there is little wear. About 20 percent of the material on the 14- and 35-mesh screens consists of coral, calcareous algae (Porolithon and Halimeda), echinoid, Homotrema, mollusk, and other fragments. The fine material is composed of fragments of the above plus a scattering of small Foraminifera (miliolids and cymbaloporids), needle-thick echinoid spines and embryonic gastropods.

Remarks: This lobe and others like it form opposite trans-reef spillways and points where sediments crossing the reef are funnelled into a narrow area. It is surprising that the spines on the Calcarina should be more broken than those on specimens collected from some of the seaward beaches, and it probably indicates that their transportation is either violent or very slow with the particles moving along the bottom of the reef flat and spillways the entire distance. The very fresh materials collected from some seaward beaches, or along the sides of islands, are for the most part high on the beaches. They were probably wafted high on the beaches by storm waves, and remained above high-tide level with very little subsequent working.

Sample 23

Sand accumulation at lagoon side of what is either an indurated rubble flat or the remainder of a raised reef flat, Bokanwor, near the east end of Ujelang Atoll.

Atoll position: The jagged flat is located at the eastern end of the reef. The reef at this point bends gently from its more northwesterly trend west of here to a more southerly trend to the easternmost tip of Ujelang islet.

Other data: The reef at this place is nearly half a mile wide. The point at which the sample was taken lies about 1,200 feet from the seaward edge, and about 200 feet lagoonward from the irregular promontory. The rough flat is submerged at high tide. Behind it is an accumulation of sand and gravel which is trapped in the lee of the irregular promontory, and which thins lagoonward.

Character:	Size (mesh)	Percent	
	3	50)	
	4	4)	coarse
	9	12)	
	14	3)	
	35	20)	medium
	less than 35	6	fine

The coarse sizes are pieces of coral and coralline algae (Porolithon) and mollusk shells, with a scattering of Halimeda segments. Well-preserved Homotrema and Carpenteria encrust many of the fragments. The fragments range from little worn to well worn and many of them are darkened by surface growths of algae. The medium sizes contain smaller fragments of the same materials, and about 50 percent Foraminifera, mainly Calcarina, Amphistegina, and Marginopora. Many of the Calcarina have spines intact. As with the coarser material, many particles are dark owing to a growth of minute algae on their surface. The fines contain fragments of the same materials with a scattering of minute Foraminifera (miliolids and cymbaloporids) and calcareous spicules.

Remarks: The materials at this place are covered with every tide. The lack of wear, which is emphasized by the algal growth on many particles, is probably due to the semiprotection of the deposit from agitation by the raised indurated flat to the seaward. A small amount of white sand can be seen extending lagoonward as a sediment train on air photographs.

Sample 24

Lagoon beach of Nelle islet, Ujelang.

Atoll position: Islet located at east side of wide pass on leeward side of atoll, just a little west of the center of the leeward reef.

Other data: Coarser material occurs on the eastern seaward corner of the islet than elsewhere. The material in the intertidal zone along the lagoon beach is mostly fine.

Character:	Size (mesh)	Percent	
	3	Tr.)	coarse
	4	Tr.)	
	9	2.5)	
	14	2.5)	medium
	35	40)	
	less than 35	55	fine*/

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*/ Fines were sieved to conform to the Wentworth Scale.

Coarser fragments are much worn pieces of coral, algae (Porolithon) and Halimeda), mollusk shells and echinoid spines. The medium-sized material consists of the same, plus a small percentage of foraminifera (Calcarina, Amphistegina, and Marginopora). The Calcarina are much worn, but some of the Amphistegina are quite fresh. The fine material consists of angular fragments for the most part. In addition to the constituents found in the coarser sizes, there are a few calcareous spicules.

Remarks: The freshness of some Amphistegina suggests that they were derived from the lagoon. The angular character of most of the fines is of interest here as on other leeward reefs. Whether this indicates that the fines are the result of local recent breaking of larger fragments, or whether it means that abrasion of the finer sizes does not take place at the same rate as the larger sizes is difficult to say. At any rate, there does not appear to be any indication of breakage on larger fragments, all of which are well worn. The most likely explanation is that the fines were washed up on the lagoon beach from the lagoon as angular fragments.

Sample 25

Sand from irregularities on raised rock platform on seaward side of Maronlik islet, Ujelang.

Atoll position: Islet located on windward (northeast-facing) reef on eastern third of atoll.

Other data: Sample from one of many sand-filled irregularities on rock platform extending seaward from islet. The spot is located about 100 feet from the seaward tip of the islet and about 700 feet from the outer reef margin.

Character:	Size (mesh)	Percent	
	3	2.5)	
	4	10)	coarse
	8	35)	
	14	25)	medium
	35	25)	
less than	35	2.5	fine

The coarser materials are mainly fragments of corals and coralline algae (*Porolithon*) with occasional echinoid spines, mollusk or *Halimeda* segments. The fragments are moderately worn, but many are darkened by a surface growth of algae, showing a minimum of active wear. Small colonies of *Homotrema* are attached to the fragments. The medium sizes are made up of similar materials, less worn, for the most part, than the coarse material, and contains in addition about 50 percent little worn to fresh *Calcarina* and *Amphistegina* with a scattering of small *Marginopora*. The spines on most of the *Calcarina* are unbroken. The fines are composed of mostly angular fragments of the above and in addition there are a few small forams (miliolids and cymbaloporids) and calcareous spicules.

Remarks: The sand and gravel in the pockets on the raised platform is little more than wetted at high tide, only occasional waves welling on to the platform and sending little streams along its natural irregularities. These find the minor depressions and fill or partly fill them, and the water eventually disappears within the porosity of the rocks. There is, therefore, very little abrasion of materials in the pockets, and they are agitated and moved beachward only during rough weather or storms when waves sweep entirely across the platform. This probably accounts for the freshness of the Foraminifera and the algal coats on some of the other fragments.

The February 1945 photos show a broad sand beach around the seaward end of this island and an elongate sand spur extending seaward along the center of the raised flat. In 1952 the sand spur had largely disappeared, only occasional pocket fillings remaining, and sand was absent from the seaward tip of the island. A medium-textured boulder beach was partially exposed.

Sample 26

Beach along west side of Maronlik islet, Ujelang.

Atoll position: Same as sample 25.

Other data: Sample from beach facing reef along west side of island. The broad seaward beach and the elongate spur extending seaward from it along the center of the raised rock flat, shown on the 1945 photos, appears to have been redistributed along the sides of the island. There is some indication, particularly from the sharpness of the lagoon beaches and the spurs extending seaward on the 1945 photos, that a storm prior to 1945 steepened the lagoon beaches, and moved island beach sands seawards, producing the seaward-pointing spurs. A subsequent storm removed the spurs and moved materials seaward again along the sides of the island. Bars at the lagoon corners extending along the reef, or possibly deflected a little seawards, were deflected strongly lagoonwards and distributed more thinly across the lagoon beach.

Character:	Size (mesh)	Percent	
	3	20)	coarse
	4	5)	
	9	7)	
	14	13)	medium
	35	55)	
less than	35	Tr.	fine

The coarse material consists of fresh to moderately worn pieces of coral, coralline algae (*Porolithon*), echinoid spines, and both whole and fragmented shells of mollusks, *Marginopora*, and *Halimeda* segments. *Homotrema* encrusts some of the algal fragments. The medium-textured material contains, in addition, about 60 percent moderately fresh *Calcarina* and a few *Amphistegina*. Although the *Calcarina* show little sign of disc wear, most specimens have the spines broken off. The fines contain numerous small forams (miliolids), fine echinoid spine fragments, and an abundance of calcareous spicules.

Remarks: For the most part the materials here are cleaner and look less worn than the material in the pockets on the rock flat to the seaward. However, the *Calcarina* in the sample from the rock flat have better preserved spines than the beach specimens.

Sample 28

Rock platform at north seaward corner of Taka islet, Taka Atoll.

Atoll position: Islet at southeast corner of atoll. Sample from pocket of gravel lodged behind a strip of abandoned beach rock.

Character:	Size (mesh)	Percent	
	3	40)	
	4	30)	coarse
	9	20)	
	14	5)	medium
	35	5)	
less than	35	Tr.	fine

Coarse material consists of moderately fresh fragments of coral, coralline algae (*Porolithon*), echinoids, mollusks, and *Marginopora*, and *Halimeda* segments. There is some darkening, probably due to algae growing on the surface. The medium sizes contain similar fragments and in addition there is 10 percent *Calcarina* and *Amphistegina* ranging from slightly worn to well preserved. There is some darkening due to algae on most particles, even the completely spined *Calcarina.* The fines contain fragments of the same materials plus a scattering of minute Foraminifera (miliolids and cymbaloporids) and calcareous spines.

APPENDIX II

Field descriptions of soil profiles or sedimentary sections

Because of a general dearth of descriptive data on atoll soils it seems desirable to record all information on the material reported in this paper just as it was written down in the field, in the form of descriptions of profiles or partial profiles. These do not correspond exactly, in certain respects, to ordinary soil profiles, as the layering is as much due to depositional phenomena, in other words, stratification, as to soil horizon development. The profiles might equally well be called sedimentary sections. However, there is in all cases some evidence of horizon development. In the Shioya and Arno Atoll series, layer 1 corresponds to an A_1 horizon and the lower layers to a C horizon. In the Jemo series, layer 1 is an A_0 horizon, layer 2, a B horizon, and the lower layers, a C horizon.

Color determinations were made under field conditions, ordinarily on somewhat moist samples, in most cases (except on Taongi (Pokak) and Bikar Atolls) by direct comparison with a Munsell color chart. Information on structure is only given if it is not the loose single-grain structure normally observed in these soils. Consistence, likewise, is not commonly mentioned, as it seems to lack significance in most of these sandy soils.

Certain of the profiles described were not analyzed, but are included here to provide a fuller basis for the generalized series descriptions.

SHIOYA SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 4			Utirik, Utirik islet, SW. corner of islet, nearer outer than inner beach (fig. 18, E).	Flat ground in open coconut grove, grassy with some bushes.
102	1	0-1.6		Reddish-gray (5YR-5/2) with some fine black (5YR-3/1), varying blotches of light-reddish-brown (5YR-6/3). Sand with irregular coral fragments.
103	2	1.6-2.2		Pinkish-gray (5YR-6/2) loamy sand with some gravel.
104	3	2.2-2.5		Pink (5YR-8/3) fine sand with some coarser particles.
105	4	2.5-3.2		Mixed pinkish grays averaging about 5YR-7/2. Gravel with some coarse sand.
No sample	5	3.2 +		Reef rock.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 3			Utirik, Utirik islet, S. of village near ocean beach (fig. 18, E).	Flat ground in open grassy coconut grove.
97	1	0-1.3		Salt and pepper pinkish (5YR-8/2, 5/1, 3/1 averaging 6/2) loose sand with irregular coral fragments.
98	2	1.3-1.9		Dark gray (10YR-3/2) loose sand with irregular coral fragments.
99	3	1.9-2.3		Pale gray-pink (5YR-8/2), loose sand with irregular coral fragments.
100	4	2.3-3.0		Pale gray-pink (5YR-8/2), darkened a little at top, loose sand with irregular coral fragments.
101	5	3.0-4.2 +		Gray (5YR-5/1) becoming lighter downward, irregularly mottled or splotched with pink (5YR-8/2-8/3). Sandy rubble with irregular coral fragments.

Then coral fragments became so numerous and hard-packed that digging became impractical. Large cobbles and even a few boulders were scattered through this entire profile.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A8 (Arnow)			Wotho, Wotho islet, 500 ft from lagoon beach (fig. 16, J).	Flat ground in coconut grove with grassy undergrowth.
23	1	0-1.4		Dark-brown (7.5YR-3/2) to brown (7.5YR-5/2). Sand, coarse to very coarse, and silt.
24	2	1.4-1.9		Very dark brown (10YR-2/2) and 10YR-7/3 mixed). Very coarse sand with small pebbles and silt covering many of the larger particles.
25	3	1.9-?		Very pale brown (10YR-8/3). Fine to coarse sand, few Foraminifera, some pebbles.
Water table		3.2		

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A7 (Arnow)			Wotho, Wotho islet, 210 ft. in from lagoon beach (fig. 18, J).	Flat ground in coconut grove.
21	1	0-1.6		Dark-brown (7.5YR-3/2) to brown (7.5YR-5/2). Coarse to very coarse sand, loamy in upper 6 inches.
22	2	1.6-?		Very pale brown (10YR-8/3). Medium to coarse sand, about 10 percent Foraminifera.
Water table		2.8		
Compact, walls stand up without caving, but easy to dig through.				
Profile 69			Wotho, Wotho islet, near center of islet (fig. 18, J).	Flat ground in *Ochrosia* forest.
141, 142, 143	1 Transition abrupt	0-1.0		Dark-gray (10YR-4/1), fine rubble varying to fine sandy loam, somewhat compact but friable.
144	2	1.0-3.0		Very pale brown (10YR-8/4) sand.
Profile 71 (partial)			Wotho, Wotho islet, on west point of islet (fig. 18, J).	Flat ground in scrub vegetation under young coconut trees.
147	1	0-0.1		Light-brownish silt (10YR-6/2), pisolites about 2-3 millimeters diameter.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 72			Wotho, Wotho islet, on west point of islet (fig. 18, J).	Flat ground in *Scaevola* scrub in sparse coconut plantation.
148	1	0-0.3		Gray to gray-brown (10YR-5/1-5/2), loosely pisolitic, silty.
149	2	0.3-0.5		Light-gray-brown (10YR-6/2) silt, compact, but fluffy when crushed.
150	3	0.5-1.8 +		Pink (7.5YR-8/2-8/4) loose sand.
Profile A26 (Arnow)			Ailuk, Ailuk islet, southwest corner (fig. 18, A).	Vegetated sand spit.
133	1	0-1.0		(10YR-8/1) light-gray-medium sand.
134	2	1.0-4.0		Coarse to very coarse sand with pebbles and small cobbles.
Profile 139			Taongi (Pokak), Kamwome islet, well inland from sea (fig. 16, C).	Middle of broad low ridge of small gravel with sparse *Messerschmidia* forest. 10YR-5/2, 10YR-3/1 + 7/2.
154	1	0-0.13		10YR-7/2, 7/3, 4/2 + 2.5Y-4.0. Darkened by organic material, small gravel.
153	2	0.13-1.1		Pale, small gravel.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 141 (partial)			Taongi (Pokak), Sibylla islet (fig. 18, D).	Shallow depression in open place, with algal film.
156	1	0-0.08		White (2.5Y-9/1-9/2) silt.
no sample	2	0.08-0.57		Sand.
Profile 144 (partial)			Taongi (Pokak), Sibylla islet, NE. end, 300 feet from lagoon beach (fig. 18, D).	Flat ground, Scaevola scrub vegetation.
no sample	1	0-1.5		Sand, slightly darkened at surface, otherwise light brown.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 145			Taongi (Pokak), Sibylla islet, about in center 1 mile from N. end of islet (fig. 18, D).	Flat ground, surface of small gravel strewn with boulders, in sparse Messerschmidia scrub.
157	1	0-0.85		Gray-brown (10YR-6/1-7/2) darkened somewhat at surface. Medium coarse sand with some coral fragments.
No sample	2	0.85-1.15		Very pale. Very fine sand with some coral fragments.
No sample	3	1.15-1.85		Gray-brown. Fine rubble.
No sample	4	1.85-2.75		Gray brown. Coarse rubble.
No sample	5	2.75-4.1		Light-pinkish. Fine rubble with some coarse fragments.
Water table		4.2		
No sample	6	4.1-5.4 +		Whitish. Semi-indurated rubble, interstices filled with very fine material.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 146			Taongi (Pokak), Sibylla islet, toward lagoon, about 1 mile from north end of islet (fig. 18, D).	Open flat ground, shearwater rookery with holes 1-1.5 meters apart, herbaceous vegetation mainly *Portulaca*.
No sample	1	0-0.03		White surface crust, strengthened by algae.
No sample	2	0.03-1.8		Light-gray-brown. Fine sand, standing up well when cut by shovel, even when dry.
No sample	3	1.8-3.2		Light-brown. Coarse rubble.
No sample	4	3.2-4.8 +		White rubble, mostly rather fine but with some large fragments, and fine claylike material between fragments.
Water table		4.5		

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 11			Taka, Taka islet, 300 feet from lagoon beach (fig. 16, E).	Flat ground in grassy opening in sparse coconut grove.
122	1	0-0.8		Whitish-pink, (7.5YR-8/2) slightly stained with organic matter in top 0.15 feet, coarse sand.
	Changing abruptly			
123	2	0.8-1.5		Salt and pepper mixture of dark-brown (7.5YR-3/2) and pinkish-gray (7.5YR-6/2) very sandy loam.
	Changing over space of 0.1			
124	3	1.5-3.0		Salt and pepper mixture averaging brown to pinkish-gray (7.5YR-3/2-6/2) sandy gravel with water-worn fragments.
	Changing abruptly			
no sample	4	3.0-?		Coarse angular rubble mixed with much sand.
no sample	5	?-?		Rock with sloping surface (beach rock?).

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 12			Taka, Taka islet, central part of islet (fig. 16, E).	Flat ground in grassy opening in mixed scrub vegetation.
51	1	0-0.9		Dark-brown (7.5YR-3/2) larger particles as light as 7.5YR-5/2-6/2, darker at top, loam sand, fluffier and with more organic matter toward top.
	Changing gradually			
52	2	0.9-1.5		Pinkish-gray (7.5YR-6/2) sand mixed with fine silt fairly compact, easily crumbled.
	Changing gradually			
53	3	1.5-4.3		Pink (7.5YR-7/4) sand to small gravel, occasional larger fragments.
no sample	4	4.3-?		Indurated limesand or beachrock.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 13			Taka, Taka islet, central part of islet (fig. 16, E).	Flat ground with *Scaevola* scrub vegetation.
54	1	0-0.25		Very dark gray (5YR-3/1) loamy sand.
	Changing abruptly			
55	2	0.25-2.0		Reddish gray (5YR-5/2) to pinkish gray (5YR-6/2-7/2) sand with some small gravel.
	Changing abruptly			
56	3	2.0-2.5		Pinkish gray (5YR-7/2) gravel with fine sand or silt.
	Changing abruptly			
57	4	2.5-4.4		Very pale brown (10YR-8/4) coarse sand with some gravel, changing to sand and large fragments in bottom 8 inches or so.
no sample	5	4.4-?		Consolidated fine gravel.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A15 (Arnow)			Taka, Taka islet, 400 feet in from outer beach (fig. 16, E).	Flat ground in clearing in mixed scrub forest.
109	1	0-0.3		Very dark gray (10YR-3/1) and very pale brown (10YR-8/3), medium sand and loam.
110	2	0.3-0.9		Gray brown (10YR-5/2), medium to fine sand.
111	3	0.9-1.4		Dark gray brown (10YR-4/2) pebbles.
112	4	1.4-1.8		Light gray (10YR-7/2), medium to fine sand.
113	5	1.8-2.1		Dark gray brown (10YR-4/2), coarse to medium sand and pebbles.
114	6	2.1-3.1		Light brown gray (10YR-6/2), coarse to medium sand and pebbles.
115	7	3.1-8.8 +		Very pale brown (10YR-8/4), fine to coarse sand with occasional small cobbles, becoming indurated in lower 3 feet.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A16 (Arnow)			Taka, Taka islet, 75 feet from lagoon beach (fig. 16, E).	Flat ground in coconut grove.
116	1	0-0.5		Very pale brown (10YR-8/3) fine to medium sand.
117	2	0.5-1.2		Gray brown (10YR-5/2) fine to very fine sand, occasional pebbles.
118	3	1.2-1.9		Very pale brown (10YR-8/3) fine to medium sand.
119	4	1.9-2.8		Light brown gray (10YR-6/2) fine to medium sand, occasional cobbles.
120	5	2.8-5.7		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size.
Water table		5.7		

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 29			Jemo Island (fig. 17, A).	Flat ground with low forest of *Scaevola* and *Messerschmidia*.
131	1	0-0.5		10YR-7/2, 7.5YR-7/2 salt and pepper averaging pale brown (10YR-6/3), lighter downward, sand, some rocks.
	Changing gradually			
132	2	0.5-2 +		Sand with pebbles and cobbles.
Profile 30			Jemo Island, near east side (fig. 17, A).	Flat open area with scattered *Scaevola* bushes.
69	1	0-0.6		Salt and pepper from very dark gray-brown (10YR-3/2) to pale brown (10YR-6/3) loamy sand.
	Changing gradually			
70	2	0.6-1.4		Very pale brown (10YR-7/3-3/3) sand.
	Changing rather abruptly			
71	3	1.4-3.0		Very dark gray-brown (10YR-3/2) including some lighter grains, general effect gray brown (10YR-4/2); lighter below first 0.5 feet, also coarser, compact but very crumbly.
72, 73	4	3.0-?		Pink (7.5YR-8/4) coarse sand with some gravel.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 103 (partial)			Ujae, Ebbetyu islet near lagoon beach (fig. 16, G).	Flat ground in coconut plantation, unburned.
121	1	0-1		Gray (10YR-4/1-4/2) sand.
Profile 104 (partial)			Ujae, Ebbetyu islet, near lagoon beach (fig. 16, G).	Flat ground in coconut plantation where pile of trash has been burned.
152	1	0-1		Gray brown.
Profile 101 (partial)			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground in *Ochrosia* forest.
89	1	0-0.5		Dark gray-brown (10YR-3/1-3/2).
no sample	2	0.5-?		Rubble.
Profile 100 (partial)			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground under *Pisonia* tree.
88	1	0-0.5		Gray-brown (10YR-3/2-4/1).
no sample	2	0.5-?		Rubble.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 17			Likiep, Lado islet, 221 feet E. of lagoon beach, 175 feet N. of south beach (fig. 16, B).	Flat ground in sparse coconut grove with thin herbaceous vegetation, barren in aspect.
125	1	0-0.6		Reddish gray (5YR-5/2) fine sand, pebbly at surface, much pebbly coral in layer.
126, 127	2	0.6-3.0		Pinkish white to pink (5YR-8/2-8/3), some lenses stained slightly grayish, sand with many water-worn pebbles and cobbles arranged in lenses or horizontally.
129, 130	3	3.0-6		White to pink (5YR-8/1-8/3) fine gravel with pebbles up to several inches across.
Water table		3.9-5.5 or lower (tidal fluctuation)		
Profile 46			Lae, Lae islet, in village 20 feet from high-tide mark on lagoon beach (fig. 18, C).	Flat ground under large breadfruit tree.
138	1	0-0.3 or 0.9		Gray (2.5Y-5/0) compact sand.
139	2	0.3 or 0.9-6.0 +		Light pinkish coarse sand.

ARNO ATOLL SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 1			Utirik, Utirik islet just E. of village (fig. 16, E).	Flat ground in open grassy coconut grove.
37	1	0-0.7		Black (10YR-2/1) flecked with pale, coarse irregular gravelly sand, some fine material.
38	2	0.7-1.1		Black (10YR-2/2) thickly flecked with pale sand.
39	3	1.1-2.7		Black (10YR-3/1) mottled with gray, coarse irregularly gravelly sand.
40	4	2.7-4 +		Very pale brown (10YR-7/3-8/3) sand.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 2			Utirik, Utirik islet, center of islet S. of village (fig. 16, E).	Flat ground in open grassy patch in coconut grove.
41	1	0-0.2		Black (10YR-2/1) thickly flecked with light brown, coarse foraminiferal sand.
42	2	0.2-0.7		Salt-pepper brown (10YR-4/2-4/3) becoming lighter downward, coarse foraminiferal sand.
43	3	0.7-1.8		Black 1YR-2/1-4/1 coarse foraminiferal sand.
44, 45	4	1.8-7		Pinkish mottled with gray, gray (5YR-6/2) to pink (5YR-8/3) coarse foraminiferal sand, loose to hard-caked (below 5 feet).
46	5	7-8 +		Small gravel.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 5			Utirik, Utirik islet, near center of islet E. of village (fig. 16, E).	Flat ground in sparse coconut grove, herbaceous vegetation knee-high.
47	1	0-0.7		Black (10YR-2/2) loamy sand with a few small coral fragments.
48	2	0.7-1.5		Gray pink (7.5YR-6/4) blotched with a salt and pepper mixture (10YR-3/1 and 6/2) appearing gray, coarse sand.
	Changing gradually			
49	3	1.5-2.5		Pink (7.5YR-8/4) blotched above with gray (as in layer 2), foraminiferal sand.
50	4	2.5 +		Pink, consolidated small gravel, easily shattered.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A3 (Arnow)			Ujelang, Ujelang islet, 80 feet from lagoon beach (fig. 17, F).	Flat ground in coconut grove.
30	1	0-1.5		Very dark brown (10YR-2/2) loamy mixture of pebbles, sand and silt, some clay, occasional cobbles.
31	2	1.5-2.4		Light gray (10YR-7/2) loamy mixture of pebbles, sand and silt, some cobbles and boulders, silt forms coating around larger particles; rather compact.
32	3	2.4 +		White (10YR-8/1) rubble of boulders, cobbles, pebbles, sand and silt, compact and hardpan-like, friable when broken loose.
Profile A14			Taka, Taka islet, 540 feet in from lagoon beach (fig. 16, E).	Flat ground in *Pisonia* grove.
106	1	0-0.9		Black (10YR-2/1) with white grains, sand and clayey loam.
107	2	0.9-3.4		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size.
108	3	3.4-4		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size, somewhat indurated.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A23 (Arnow)			Ailuk, Ailuk islet (fig. 18, E).	Flat ground in grassy coconut grove.
33	1	0-1.2		Very dark gray (7YR-3/0) loam and sand with pebbles and cobbles, mostly water worn.
34	2	1.2-1.7		Very pale brown (10YR-7/3) medium to coarse sand.
35	3	1.7-2.4		Dark gray (10YR-4/1) compact silt and medium sand, occasional larger particles.
36	4	2.4-4.3		Very pale brown (10YR-8/3) coarse to very coarse sand with pebbles and cobbles; pockets of silt and with clay acting as binder in lower 1.5 feet where it is indurated.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 38			Ailuk, Ailuk islet, near village (fig. 18, A).	Flat ground in open coconut grove, most trees dead or dying ("laora" disease?).
77	1	0-1.0		Black (5YR-2/1) sandy loam with some small gravel.
	Changing abruptly			
78	2	1.0-1.8		Pink (7.5YR-7/4) with a few black spots, foraminiferal sand.
	Changing abruptly			
79, 80	3	1.8-2.7		Pink (7.5YR-7/4) fine gravel, compact.
81	4	2.7-3.0		Very pale brown (10YR-7/3) silt, compact, slightly plastic when worked between fingers.
82	5	3.0-3.7 +		Very pale brown (10YR-7/3-8/4) small gravel with some larger fragments, poorly consolidated, shatters easily.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile All (Arnow)			Lae, Gibinrii islet, in center of islet, 120 feet from lagoon beach (fig. 18, C).	Flat ground in coconut grove.
272	1	0-0.6		Very dark brown (10YR-2/2) loam or loamy sand.
273	2	0.6-1.4		Pinkish gray (7.5YR-6/2) very coarse sand, mostly Foraminifera, occasional pebbles.
no sample	3	1.4-1.7		Pebbles and some loam.
no sample	4	1.7-2.2		Pebbles and some loam.
274	5	2.2-2.5		Gray (10YR-6/1) water-worn pebbles.
275	6	2.5-5		Reddish yellow (7.5YR-8/6) and very pale brown (10YR-8/3) very coarse sand, strongly indurated at 3.5 feet below which are alternating hard and soft zones.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 18			Likiep, Lado islet, back of seaward ridge (fig. 16, B).	Broad depression in grassy coconut grove.
58	1	0-1.3		Black to dark reddish brown or very dark gray (5YR-2/1-3/1) coarse sand and silt with much coarse gravel.
	Changing gradually			
59	2	1.3-2.5		Pink (7.5YR-8/4) coarse foraminiferal sand with coral fragments as much as several inches.
	Changing gradually			
60, 61	3	2.5-3.9 +		Fine gravel.
Water table		3.5		
Profile A9 (Arnow)			Wotho, Wotho islet, 650 feet from lagoon beach (fig. 16, J).	Flat ground in cleared area overgrown by *Wedelia*.
27	1	0-1.0		Very dark brown (10YR-2/2) mixture of silt, sand and small pebbles.
28	2	1.0-2.0		Light brown gray (10YR-6/2) coarse to very coarse sand and pebbles.
29	3	2.0-5.0		Very pale brown (10YR-8/4) sand and pebbles, semi-indurated.
no sample	4	5.0-?		Solid reef rock.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 70			Wotho, Wotho islet, center of islet (fig. 16, J).	Flat ground on boundary between coconut plantation and *Ochrosia* forest.
145	1	0-1.0		Dark gray (10YR-4/1) fine powdery loam varied in places with small lenses of light-colored sand.
	Changing somewhat gradually			
146	2	1.0-1.7 +		Light brownish-gray (10YR-6/2-7/2) very compact fine rubble.
Profile 84			Ujae, Bock islet, near lagoon (fig. 17, C).	Flat ground in coconut plantation.
86	1	0-0.5		Black (10YR-2/1) silt mixed with lighter grains of sand and fine rubble.
no sample	2	0.5 +		Rubble.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 27			Jemo Island (fig. 17, A).	Flat ground in dense coconut grove, herbaceous ground cover.
63	1	0-0.7		Black (10YR-2/1) silt with some gravel.
64, 65	2	0.7-1.1		Black with conspicuous white grains, mixture of silt and rubbly fragments.
66	3	1.1-2.4		Salt and pepper mixture of dark gray (10YR-4/1) and light brown gray (10YR-6/2) loamy sand.
67, 68	4	2.4-?		Very pale brown (10YR-8/3) very coarse sand.
Profile 98 (partial)			Ujae, Wotya islet (fig. 16, I).	Flat ground in *Ochrosia* forest.
87	1	surface (thickness not recorded)		Dark brown (7.5YR-3/2) crumbly fine material with some fine fragments.
	Changing abruptly			
no sample	2			Loose rubble.

JEMO SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 123-125 (partial)			Wotho, Kabben islet, near center of eastern half of islet (fig. 18, F).	Flat ground under large *Pisonia* trees.
196, 197	1	0.5(or 0.2)-0		Black to brown raw humus.
198, 199	2	0-0.5		Blackish loose crumbly soil with much rubble.
Profile 118 (partial)			Wotho, Ombelim islet (fig. 17, H).	Flat ground in *Pisonia* forest, covered by dry leaves.
194	1	0.1-0		Black raw humus with hard black surface.
195	2	0-0.2		Partially cemented sand.
no sample	3	0.2 +		Sand.
Profile 116-117 (partial)			Wotho, Ombelim islet (fig. 17, H).	Flat ground in *Pisonia* forest, covered by dry leaves.
192	1	0.3(to 0.2)-0		Raw humus.
193	2	0-0.2		Partially cemented sand.
no sample	3	0.2 +		Sand.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 110 (partial)			Ujae, Erlie islet (fig. 16, F).	Flat ground in Pisonia grove.
190	1	0.5(to 0.25)-0		Raw humus, surface bumpy, hardened and cracked polygonally.
191	2	0-0.1(to 0.15)		Partially consolidated material.
no sample	3	0.1(to 0.15) +		Coral rubble.
Profile 97 (partial)			Ujae, Wotya islet (fig. 16, I).	Flat ground in Pisonia grove.
224	1	0.25(to 0.1)-0		Dark reddish brown (5YR-3/1-3/2) mottled with light grayish flecks and patches, raw humus; 4 Truog tests: pH 4.5-5.
225	2	0-0.1		Mottled dark brown and light partially consolidated material, hard but crumbling between fingers; 2 Truog tests: pH 6.0(1), 8.0(1).
no sample	3	0.1 +		Rubble of small pebbles.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 86-87 (partial)			Ujae, Bokerok islet (fig. 17, D).	In *Pisonia* grove on boulder flat.
218, 220	1	0.3-0		Raw humus.
219, 221	2	0-?		Weakly consolidated sand (219); partially altered pebbles (221).
no sample		0-?		Boulders.
Profile 91 (partial)			Ujae, Rua islet (fig. 16, H).	In *Pisonia*-*Terminalia* grove.
222	1	0.4-0		Raw humus; 8 Truog tests: pH 5.5-6.5.
223	2	0 +		Hardpan of consolidated sand.
Profile 73 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
210	1	0.2(to 0.4)-0		Raw humus.
211				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0+		Rubble.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 74 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
212	1	0.4(to 0.2)-0		Raw humus.
213				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0 +		Rubble.
Profile 78 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
214	1	0.4(to 0.2)-0		Raw humus; Truog test: pH 5.
215				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0 +		Rubble.
Profile 79 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
216, 217	1	0.5-0		Light-brown raw humus with included pebbles, these altered and ocherlike externally. Truog test of pebbles: pH 8.
no sample	2	0 +		Rubble.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 15			Taka, Lojrong islet (fig. 16, D).	Flat ground in *Pisonia* grove.
201	1	0.25-0		Black to dark-brown raw humus with Foraminifera and coral fragments; Truog test: pH 8.0.
no sample	2	0 +		Coral gravel.
Profile 14			Taka, Lojrong islet (fig. 16, D).	Flat ground in *Pisonia* grove.
200	1	0.25(to 0.15)-0		Tough, compact dark-brown raw humus; 2 Truog tests: pH 5.5(1), 6.0(1).
no sample	2	0 +		Coral gravel.
Profile 134			Taongi (Pokak), Kamwome islet (fig. 16, C).	Flat ground in *Pisonia* clump, closely strewn with *Cardium* shells.
no sample	1	0.1-0		Poorly formed raw humus.
Do.	2	0-0.9		Brown fine sand.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 28			Jemo island, west side (fig. 17, A).	Flat ground in grassy *Pisonia* grove.
202	1	0.4-0		Very dark brown (10YR-2/2) raw humus, tough but friable when crushed firmly. 2 Truog tests: pH 5.0(2).
203	2	0-0.3		Variable light and brown, averaging yellowish brown (10YR-6/4) coarse sand, weakly cemented, crumbling between fingers.
204	3	0.3-?		Very dark gray-brown (10YR-3/2) with light grains, loamy sand.
Profile 26			Jemo island, west side (fig. 17, A).	Flat ground in *Pisonia* grove.
4	1	1-0		Dark-reddish brown (5YR-2/2-3/2) raw humus; 3 Truog tests: pH 4.5(3).
5	2	0-?		Very dark brown matrix (10YR-2/2) with white grains, coarse rubble of fragments of cemented material.
Profile 31 (partial)			Jemo Island, west side (fig. 17, A)	Flat ground in coconut grove.
205	2	surface		Exposed surface layer.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 32 (partial)			Jemo island, west side (fig. 17, A).	Flat ground in coconut grove.
6	2	surface		Exposed surface layer.
Profile 25			Jemo island, west side (fig. 17, A).	Flat ground in *Pisonia* grove.
1	1	0.5-0		Dark-reddish-brown (5YR-2/3-2/2) fine raw humus; Truog test: pH 6.5.
2	2	0-0.3		Matrix very dark brown (10YR-3/2) grains white (10YR-8/2), cemented coarse sand.
3	3	0.3-1.5 +		Very dark brown (10YR-2/2) with tiny white grains, sandy loam with gravel, more rubbly downward.
Profile 177 (partial)			Bikar, Bikar islet (fig. 18, B).	Flat ground in *Pisonia* forest.
228	1	0.5-0		Raw humus.
229	2	0-0.25		Consolidated layer.

These separated by a thin deposit of yellow-brown earthy material.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 156			Bikar, Bikar islet (fig. 18, B).	Flat ground, covered by litter, in *Pisonia* forest.
176	1	0.15-0		Very dark brown raw humus; 12 Truog tests: pH 4.5(2), 5.0(3), 5.5(1), 6.0(6).
177	2	0-0.1		Pale sand with dark brown cement; consolidated.
178, 179	3	0.1-0.6		Gray brown, streaks stained dark brown, finely and irregularly bedded sand.
180, 181	4	0.6-1.2		Dark gray brown, with (consolidated) layers of brown; sand with irregular consolidated layers.
182	5	1.2-2.5		Darker gray loose sand with brown lumps of cemented sand and thin layers of slightly darker material.
183, 184	6	2.5-3.9		Very dark brownish gray to brown, earthy, powdery, sandy, to consolidated (consolidated portion with dark-brown cement).
185	7	3.9-4.5-4.8		Pinkish ashy gray changing downward to pale brown, sand, compact above to loose below.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 156 (cont'd)				
186, 187	8	4.8-8.8		Pale-gray-brown, gravel layers humus stained; series of thin beds of alternating sand and small gravel, sand layers 2-3 inches thick, gravel thinner, all loose but gravel more compact than sand.
188	9	8.8 +		Hard rock.
Profile 153			Bikar, Bikar islet (fig. 18, B).	Flat ground, covered by litter, in *Pisonia* forest.
12	1	0.15(to 0.1)-0		Very dark brown raw humus.
13	2	0-0.1		Brown and pale salt-and-pepper consolidated layer.
14	3	0.1-1.2 +		Light-brown sand.
Profile 166			Bikar, Jabwelo islet (fig. 16, A).	Flat ground in *Pisonia* forest.
15	1	0.4-0		Dark-brown raw humus.
16, 17	2	0-0.6		Hardpan.
18	3	0.6-1 +		Pale sand and rubble.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 164			Bikar, Almani islet (fig. 16, A).	Flat ground in *Pisonia* forest.
164	1	0.4-0		Very dark brown raw humus.
165	2	0-0.25		Cemented sand.
166	3	0.25-0.6 +		Pale brown sand.
Profile 163 (partial)			Bikar, Almani islet (fig. 16, A).	Flat ground in *Pisonia* forest.
160	1	0.5-0		Loose dark brown raw humus.
161	2	0-0.5 +		Cemented sand.
Profile 165 (partial)			Bikar, Jabwelo islet (fig. 16, A).	Flat ground in *Pisonia* forest.
19	1	0.7-0		Dark-brown raw humus.
20	2	0-0.5		Cemented sand, very hard.
Profile 157 (partial)			Bikar, Bikar islet, near east side (fig. 18, B).	Flat ground in *Pisonia* forest.
162	1	0.16-0		Raw humus.
163	2	0-?		Cemented sand.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 158 (partial)			Bikar, Bikar islet, near center (fig. 18, B).	Flat ground in *Pisonia* forest.
158	1	0.2-0		Raw humus; 13 Truog tests: pH 5.0(3), 5.4(2), 5.6(1), 6.0(2), 6.5(5).
159	2	0 +		Cemented sand.
Profile 49 (partial)			Kwajalein, Eniwetak islet.	Flat ground in *Pisonia* forest.
7	1	0.5(to 0.3)-0		Raw humus.
8	2	0 +		Cemented layer.
Profile 50			Kwajalein, Eniwetak islet.	Flat ground in *Pisonia* forest.
9				Nodules of cemented material on surface.
11	1	0.5-0		Raw humus.
10				Nodules of cemented material embedded in humus layer.
Profile 55, 56 (partial)			Ujelang, Kiriniyan islet, in interior (fig. 17, E).	Flat ground in *Pisonia* grove.
207	1	0.1-0		Raw humus.
208	2	0-?		Coarse sand.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 57 (partial)			Ujelang, Kiriniyan islet, in interior (fig. 17, E).	Flat ground in *Pisonia* grove.
209	1	0.1-0		Raw humus.
no sample	2	0-?		Loose rubble.

MISCELLANEOUS PROFILES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A7 (Arnow)			Lae, Lae islet (fig. 18, C).	In taro pit.
266	1	0-0.5		Very dark brown (10YR-2/2) silt with occasional sand particles.
267	2	0.5-0.8		Very pale brown (10YR-7/3) and dark gray (10YR-4/1) silt and coarse to very coarse sand.
268	3	0.8-2.5		Very pale brown (10YR-7/4), coarse to very coarse sand and pebbles.
Profile A8 (Arnow)			Lae, Lae islet, near lagoon beach (fig. 18, C).	Taro patch.
269	1	0-0.5		Very dark gray (5YR-3/1) slimy jellylike silt with occasional sand particles.
270	2	0.5-0.9		Very dark brown (10YR-2/2) silt with fine to medium sand and occasional coral pebbles.
271	3	0.9-1.5		Very pale brown (10YR-8/4) coarse to very coarse, sand with some pebbles.

Water table at about 1 foot.

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A10 (Arnow)			Lae, Enemanman islet, 225 feet from lagoon beach (fig. 18, C).	Flat ground in coconut grove.
74	1	0-0.5		Dark-brown (7.5YR-3/2) loamy mixture of silt and coarse to very coarse sand (largely Foraminifera).
75	2	0.5-2.2		Pinkish-gray (7.5YR-6/2) sand with occasional pebbles (mostly Foraminifera).
76	3	2.2-3.8		Reddish yellow (7.5YR-8/6) and very pale brown (10YR-8/3), very coarse sand, largely Foraminifera and mollusk shell fragments.
Water table		3.5		
Profile 83			Ujae, Bock islet, near center of west part of islet (fig. 17, C).	Flat ground in coconut plantation.
151	1	0-1.5		Dark-gray (7.5YR-3/2), fine sand.
no sample	2	1.5 +		Rubble.

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 81 (partial)			Ujae, Bock islet, interior (fig. 17, C).	Flat ground in coconut grove where coconut trash has decomposed.
84	1	0.4(to 0.2)-0		Black (10YR-2/1) humus with light sand grains.
no sample	2	0-?		Loose rubble.
Profile 82 (partial)			Ujae, Bock islet, interior (fig. 17, C).	Bottom of small depression 1 meter deep in coconut grove.
85	1	0-0.5		Dark-brown (7.5YR-3/2) plastic mucky material, highly humic.
no sample	2	0.5-?		Loose rubble.
Profile 102			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground in *Ochrosia* forest.
90	1	0-0.1		Black (10YR-3/1).

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 6			Utirik, Utirik islet, east of village (fig. 18, E).	Abandoned taro pit, filled with *Clerodendrum* thicket.
256	1	0-1.9		Black (10YR-2/1-2/2) mucky loam with some coarse sand; plastic when worked.
257	2	1.9-2.5		Gray (10YR-4/1) thickly flecked with pale brown (10YR-7/3), sticky silty sand with much coral gravel.
258	3	2.5-3.2 +		Pale brown (10YR-7/3), hard, firmly packed rubble with some sand.

Water table at about 3 feet, water with strong hydrogen sulfide odor, and a peculiar sweet taste, rose to 2.3 feet in 2¼ hours. Taro pit bottom perhaps 6 feet below level of surrounding area.

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A21 (Arnow)			Ailuk, Ailuk islet, not far from outer beach (fig. 18, A).	Depression (old taro pit?) in coconut grove, ground covered with *Clerodendrum*.
263	1	0-0.9		Very dark brown (10YR-2/2), compact silt with some medium to coarse sand.
	Changing gradually			
264	2	0.9-2.5		Dark gray (10YR-4/1), compact slippery silt with numerous medium to coarse sand particles.
Water table at 2.2 feet at 11:00 a.m., January 27, 1951.				
265	3	2.5-3		Very pale brown (10YR-8/3), coarse to very coarse sand.
Profile 138			Taongi (Pokak), north end Kamwome islet (fig. 16, C).	Guano deposit in bird rookery.
sample lost	1	0-0.1		Guano--gray, firm, somewhat greasy. pH 5.5-6 (field determination with Truog indicator kit).
sample lost	2	0.1-0.3		Loosely caked earthy material, gray-brown, somewhat greasy, pH 7.
155	3	0.3-1.8		Loose gray-brown sand, pH 8.
no sample	4	0.8		Rubble.

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APPENDIX III

Synonymy of place names

Since many of the place names used in this paper, in accordance with decisions issued by the U.S. Board on Geographic Names, differ from those used by Fosberg and others (1956) and especially from those commonly used by people in the Marshall Islands, the following lists have been prepared. The left-hand list contains all names used on maps in the present paper and are approved by the Board on Geographic Names. The center list is of the corresponding names used in 1956. The right-hand list is somewhat modified from a list supplied by E. H. Bryan, Jr., of names obtained from Marshallese informants. In all cases the names on a single line apply to the same islet or other feature. Where several spellings were listed by Bryan one has been selected and the others placed in parentheses. Blanks indicate that there is no name in the particular list for the feature indicated on the line.

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Taongi Atoll	Taongi Atoll	Pokak
North Island	North	---
Kamwome	Kamome	---
Bwdije	Breje	Breje
Sibylla	Sibylla	---
Pokak	Pokak	Pokak
---	---	Bokdik
Bwokwla	Boklā	Boklā
Pokak Pass	Pokak Pass	---
Bikar Atoll	Bikar Atoll	Bikar
Jabwelo	Jaboerukku-tō	Jalliklik (Jenilklik)
Almani	Arumeni-tō	Almeni
Jaboero	Jaboerukku-tō (changed in Errata to Jaboero-tō)	Jaboero
Bikar	Bikar	Bikar
Bikar Passage	Bikar Pass	---
Ailuk Atoll	Ailuk Atoll	Ailuk
Kapen	Kapen	Kapen
Enijabro	Enijabrok	Enijabrok
Amwo	Amo	Amo
Enejelar	Enejelar	Enejelar
Jeloklap	Jeloklap	Jeloklap
Enenpao	Enenpao	Enenpao
Bikonmenlok	Bikommenlok (2 small islets)	Bikōnmenlok
Enekelik	Enekelik	Enekelik
Bigen	Bigen	Bikon

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Ailuk Atoll (continued)		
Bwinejrak	Binejrak	Binejrak
Eneneman	Enemen	Enenemman
Anenoomw	Enen-om	Enen-om
---	---	Ajatak
Ajeleb	Ajeleb	Ajillep
Ajiddik	Ajirrik	Ajirrik
Anearmij	Enearmij	Enearmij
Anekinge	Enenkone	Enenkone
Abta	Ebta	Ebta
Jabta	Jebta	Jebta
Kabbwok	Kabbok	Kabbok
Mwalok	Malok	Malok
Aliet	Aliej	Aliej
Allirik	Allirok	Allirok
Bwokwanmwiokan	Bokanmweokan	Bokanmweokan
Jerongkan	Jirongkan	Jirongkan
Aneanij	Mutōkin	Mutōkin
Anejamwaden	Enejomaren	Enejōmaren
Baojan	Baojen	Baojen
Luujrik	Lujirok	Lujirōk
Bokrak	Bōkrak	Bōkrak
Biklab	Bōklap	Bōklap
Anine	Enine	Enine
Bio	Bieo	Bieo
Bererjan	Bererjan	Bwerōrkan
Ni	Ni	Ni
Tabu	Tabu	Tabu
Konnon	Kōnwon	Kōnwon
Jobeik	Jabeik	Jebeik
Nge	Ne	Nge
Anenkora	Enenkōra	Enenkōra
Ulika	Ulika	Ulika
Jibanngit	---	Jabanngit
Maribw	Maruppu-tō	Marib
Marme	Marme	Marme
Anenkinge	Enenkōnge	Enenkōnge
Aneaudik	Eneaurik	Eneaurik
Miemwa	Miemwa	Mienwa
Eneao	Eneao	Eneao
Anemwanmwan	Enemōnmong	Enemōnmong
Jabwe	Jabbwi	Jabbwi
Anenlik	Enellik	Enellik
Ailuk	Ailuk	Ailuk
Enije	Enije	Eneje
Enije Channel	Enije Channel	Toweje
Agulwe	Agulue	Akulwe
Erappu Channel	Erappu-suidō	Tolap
Marok Channel	Marok Channel	Ton Maluk
Eneneman Channel	Eneneman Channel	Ton Eneman

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll	Kwajalein Atoll	Kwajlen
Ebadon	Ebadon	Ebaten
Bokan	Bokan	Bokan
Aoj	Aoj	Aoj
---	---	Enenak (Elenak)
Enealo	Eneao	Eneao (Enealo)
Bikrik	Bikrik	Bikrik
Nennar	Nennar	Nennar
---	---	Tabta
Jein	Jein	Jein
Mejatto	Mejatto	Mejetto
Oreba	Oreba	Keko
Bokliplip	Bokliplip	Bokliplip
Geiga	Geiga	Enejebro
Marsugalt	Marsugalt	Malik (Boklap)
Bok	Bok	Bok
Maj	Maj	Maj (Mai)
Biggerann	Biggerann	Arbwa
Elcharai	Etcharai	Ejjela (Ejjellā)
Morenkul	Morenkul	Morenkul (Mōrōnkul)
Oniotto	Oniotto	Onwot (Wōnwōt)
Biggarenn	Biggarenn	Bikram (Bekram)
Bigi	Bigi	Bikren
Bokkumaruchi	Bokmaruj	Bokmaruj
Boggerik Passage	Boggerik Pass	---
Boggerik	Boggerik	Errob (Errop)
Boggerlap	Boggerlap	Boklab (Boklap)
Mellu Pass	Mellu Pass	Milu [pass]
Drenaenae (sand bank inside pass)	Drenaenae	Drenaenae
Mellu	Mellu	Milu
North Pass	North Pass	---
Ennuebing	Ennuebing	Enibing (Enebin)
Roi	Roi	Ruot
Namur	Namur	Nimur
Ennugarret	Ennugarret	Enekoran (Enekōren)
---	---	Bokanlabirka
Ennumennet	Ennumennet	Enemanet
---	---	Bikenwot
Ennubirr	Ennubirr	Enebōn
Bogeri	Boker	Boker
---	---	Bokabelbel
Obella	Obella	Obel (Wobel)
Begeraburappu	?	---
Edgigen	Edgigen	Ajkan
Debuu	Debuu	Tubwuj

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll (continued)		
Edjell	Edjell	Ejel
Gagen	Gagen	Kowakkan
---	---	Tahemujokan (Tokāmujken)
Gellinam	Gellinam	Kirenen
Omelek	Omelek	Komle
Kwadack	Kwadack	Kwateb (Kuatab)
Eniwetak	Eniwetak	Eniwetak
Meck	Meck	Meik
Bigej	Bigej	Bikej
Bigej Channel	Bigej Channel	Bikej [pass]
Ningi	Ningi	Ngenge
Gugegwe	Nōngejokenen	Nōngejōkenen
Ebwaj	Ebwaj	Ebwaj (Ebwoj) (3 islets above form Gugegwe)
---	---	Bijinkur
Loi	Loi	Lojjaiong (N. Loi)
Lojjairok	Lojjairok	Lojjāirok (S. Loi)
Ebeye	Ebeye	Ebeye (Ebeje, Ebeja)
Ebjapik	Ebjapik	Ebjapik (Ebja drik)
Worbab	Worbāb	Worbāb
Kwajalein	Kwajalein	Kwajlen Jittaken (N arm) Jittoen (SW curve)
Enubuj	Enubuj	Enebuoj (Enibuōj)
South Pass	South Pass	---
Ennylabegan	Ennylabegan	Enelapkan
Gea	Gea	Kio (Kiio)
Gea Pass	Gea (Kio) Channel	Kio (Kiio) [pass]
Ninni	Ninni	Nini
Gehh	Gehh	Kā
Torrutj	Torrutj	Bok
---	Tongle	Tongle (Tengle)
---	Tarwoj	Tarwoj (Tarwojion, Tarwōjirōk)
Mann	Mann	Man
Jokouj	---	Jokouj (Jokouij)
South Ambo Channel	South Ambo Channel	---

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll (continued)		
Legan	Legan	Amboirok and Amboiōng (2 islets joined)
Ambo Channel	Ambo Channel	---
Eller	Eller	Ellep (Alep)
Eller Passage	Eller Pass	---
Ennugenliggelap	Ennugenliggelap	Enekanliklal (Enekanliklōl)
Burle	Burle	Murle
Onemak East Passage	East Onemak Pass	---
Labo	Labo	Labo
Onemak	Onemak	Onmak
Onemak West Passage	West Onemak Pass	---
Illeginni	Illeginni	Likijjine (Likijinā)
Wojejairok	Ujajiirukku-tō	Wojejairok (Wojejārirok)
Wojejairok Pass	Ujajiirukku Pass	---
Wojejaiong	Wojejaiong	Wojejāiōng
Jiee	---	Jā
---	---	Rebweiu (Drebwin)
---	---	Jerak
Nell	Nell	Nel (Nōl)
Nell Passage	Nell Pass	---
Bikennel	Bikennel	Bikennel
Ennumet	Ennumet	Enmat
---	---	Bokālum (Bokaliom)
---	---	Enero (Enuero)
Jakeru	Jakeru	Enejore
Gurer	Gurer	Jakrout
Eru	Eru	Ero
Gegibu	Gegibu	Kurōr
Boggenatjen	Kijin-bwi	Kijin-bwi
Ere	Ele	Ele
Bokanaujjor	Boggenatjen	Bokanaujjor
Lobon	Ere	Lobon (Lobwom)
Yabbenohr	Yabbenohr	Jabōnwōr (Japōnwōr)
Tabik Channel	Tabik Channel	---
Tabik	Tabik	Jabok
Lae Atoll	Lae Atoll	Lae
Ribong	Ribong	Ribon (Ribūn)
Nabon	Nabōn	Nabōn
Bigilapij	Bigilapij	Bikelabet (Bikelabot)
Bui	Bui	Bwi (Bwe)
Leip	Reipu	Lep (Leep)
Bigenaj	Bikenaj	Bikenaj

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Lae Atoll (continued)		
Luisap	Luisap	Lwejap (Loejap)
Enemanit	Enemanet	Enejelto (Enijeldu, Enejaltou)
Enejalto	Enejelto	Enemanet
Eonbiji	Eonbeje	Eonbeje
Nokkweie	Nokkweie	Nokkweie
Gibinrii	Gibinrii-tō	Enen-bao (Arkarek)
Enemanman	Enemanman	Enemanman (Enemōnmōn)
Lae	Lae	Lae
Rarime	Rarime	Rama, Drame
Bokanaetok	Bokanaetok	Bokanaetok (Bokanatok)
Bokankiren	Bokankiren	Bokankiren
Boklimairek	Boklimairik	Boklimairik
Boklulu	Boklulu	Boklulu
Lotj	Lotj	Loj
Lae Pass	Lae Pass	---
Likiep Atoll	Likiep Atoll	Likiep
Mwaat	Mat	Mat
Jenokae	Senegai	Senegai
Malle	Melle	Melle
Emejiwan	Rikuraru-tō	Emijwa
Rere	Rere	Rere
Pokonjieij	Pokonjieij	Pokonjieij
Aej	Aij	Aij
Kekeron	Kekeron	Kekeron
Kidenkan	Kerenegan	---
Anenaan	Eninōn	Eninōn
Enejelol	Enejelōl	Enejelōl
Anejaej	Enejeij	Enejeij
Kaben	Kaben	Kaben
Anenemmwaan	Eneneman	Eneneman
Enruk	Enruk	Enruk
Mak	Mak	Mak
Jeltonet	Jeltonet	Jeltoniej
Bikinmingjaiing	Bikirkirjeiōng	Bikirkirjeiōng
Bikinmingjairik	Bikirkirjeirok	Bikirkirjeirōk
Boguraburabu	Boguraburabu	Boklaplap
Anerukkanjaiing	Enerukanjeiōng	Enerukonjeiong
Anerukkanjairik	Enerukanjeirōk	Enerukonjeirok
Kijjen	Kojjen	Kojjen
Tamwol	Tamōl	Tamōl
Kabwolbwolkan	Kabelbelkan	Kabelbelkan
Didi	Riri	Riri
Bwokwankowak	Bokankowak	Bokankowak
Najbwol	Najbol	Najbol
Eniiecchi	Eniiecchi	Eniej
Killommwar	Melemmar	Melemmar

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Likiep Atoll (continued)		
Meron	Meron	Melang
Jibal	Jebal	Jebal
Kile	Kōle	Kōle
Anekira	Enekura	Enekura
Anearmej	Enearmij	Enearmij
Biebe	Biebe	Biebe
Mwikil	Mukil	Mukil
---	---	Aujarej
Lado	Lado	Lato
Likiep	Likiep	Likiep
Nalab	Nalap	Nalap
Nadik	Narik	Narik
Anenanuun	Enenuan	Enenuan
Aneloklab	Enenloklab	Enenloklap
Biketokeak	Biketōkāk	Biketōkāk
Biketolong	Biketolon	Biketolon
Atotak	Atolak	Atolak
Agony	Agony	Aekōne
South Pass	South Pass	---
Entrance Island (inside pass)	Entrance Island	---
Etoile	Etoile	Eotōle
Lukunor	Lukunor	Lukōnwōr
Anal	Anel	Anel
Tokaen	Tōkaen	Tōkaen
Matten	Matten	Matten
Kapenor	Kapenor	Kabinwōr (Kabinwōd)
Bokelan	Bokelan	Boklang
Rongelab	Rongelap	Ronglap
Northwest Passage	Northwest Pass	---
Rongerik	Rongerik	Rongrik
Taka Atoll	Taka Atoll	Taka
---	---	Bok (coral patch)
Waatwerik	Watourikku-tō	Elluk (Allok)
Lojrong	Lojiron	Lojiron
Taka	Taka	Tōke
Eluk	Eluk	Watwerok (Waitwerok, Wotwerok)
Bwokwen	Boken	Boken
Taka Passage	Taka Pass	Tōke [pass]
---	---	Jōjakikikan [pass]
Ujae Atoll	Ujae Atoll	Ujae
Enylamieg	Enylamieg	Enelamōj
Biginnigar	Biginnigar	Bikenkar (Bokōnkar)
Erlie	Erlie	Alle (Arle)

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Ujae Atoll (continued)		
---	---	Bokarik (Bok)
Bik	Bikku-tō	Bik (Bok)
Ebbetyu	Ebbetyu	Ebeju (Ebāju)
---	---	Letko (reef to west)
Anuij	Anuij	Anuij (Anus)
Rua	Rua	Ruōt
Wotya	Wotya	Wojia (Wōjjak)
Langeba	Langeba	Lōngba (Langba)
Naenlap	Naenlap	Naenlap
Ujae	Ujae	Ujae
Bokerok	Bokerok	Bokerok (Bōkārok)
Bock Channel	Bock Channel	Bok [pass]
Bock	Bock	Bok
---	---	Latarbōn (reef patch inside channel)
Nanmera	Nanmera	Nanmera
Bokankiru	Bokankiru	Bokankiru
Todrik Pass	Todrik Pass	Todrik (To Rik)
Tolap Pass	Tolap Pass	Tolap
Tonjure Pass	Tonjure Pass	Tonjure
Ujelang Atoll	Ujelang Atoll	Ujelang
Pyokon	Pyokon	Bikom
---	---	Bok (sand spit)
Boggelininlapp	Boggelininlapp	Bokōnenellap
Seroko	Seroko	Jerko
Pokon	Pokon	Bokan (Bokanjuakak)
Bokanibop	Bokanibop	Bokanibwiebiong
Bokanibwiebirok	Bokanibwiebirok	Bokanibwiebirok
Kilagen	Kilagen	Kiloken
---	---	Bokanjoio
Bokankemej	Bokankemej	Bokankemej
Bokanalap	Bokanalap	Bokanalap
Maronlik	Maronlik	Madromedik
Maron	Maron	Madron
Enetobal	Morina	Enetobal
Daisu	Daisu	Raej
Bokanwor	Bokanwōr	Bokan wōr
Ujelang	Ujelang	Ujelang
---	---	Enekonge
Eneraj	Eneraj	Eneraj
Burle	Burle	Bieto
Narrow Pass	Narrow Pass	---
Nelle	Romu	Nelle
Wide Pass	Wide Pass	---
Einmlapp	Einmlapp	Enellap (Einmlapp)

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Ujelang Atoll (continued)		
Ennimenetto	Ennimenetto	Enimoni (Enemanet)
Kiriniyan	Kiriniyan	Kiriniyan (Kirenen)
Kalo	Kalo	Kalo
Utirik Atoll	Uterik Atoll	Wutrok
---	---	Emijwa (sand bank)
Piji	Pije	Bike
Allok	Elluk	Elluk (Allok)
Pigowak	Pigowak	Bekrak (Bekrōk)
Nalab	Nalep	Nalap
---	---	Najā
Utirik	Uterik	Wutrok
Addibkwan (peninsula)	Adropkan	Adropkan [peninsula]
Anearemej	Eneormij	Eneormij
Bwokwarmej	Bokarmij	Bokarmij
Menetoon	Ajanen	Ajanen
Aon	Aon	Aōn (Awan)
---	---	Kōbbar
---	---	Rereti
Utirik Passage	Uterik Pass	---
---	---	Likkirukan
---	---	Korikrikloken
---	---	Bukilaen
---	---	Borankwet (the 4 above are small patches on the W reef)
Wotho Atoll	Wotho Atoll	Wotto
Medyeron	Medyeron	Mejurwōn (Majurwon)
Worrbar	Worrbar	Enebarbar
Mokeromok	Mokeromok	Eneobnāk
Enerikan	Enerikan	Enerikan
Wotho	Wotho	Wotto
		Jitninean (N part of Wotto)
		Jitrokean (S peninsula of Wotto)
Boker	Boker	Boker
Boklabunlik	Boklabunlik	Boklabunlik (Enedrik Kan)
Bokanaetok	Bokanaetok	Bokanaetok (Bokōnaetok)
Lojan	Lojan	Lojwa
Jebenau	Jebenau	Jibnao (Jibnau)
Uditj	Editj	Utiej (Wutiej)

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Wotho Atoll (continued)		
Erotjeman	Erotjeman	Iroijeman
Yeldo	Yeldo	Enejelto
Kabben	Kabben	Kaben
Eirek	Eirek	Eneairik (Eneaidrik)
Ombelim Channel	Ombelim Channel	Ombelim (Anbwilen) /pass/
Ombelim	Ombelim	Ombelim (Anbwilen)
Begin Channel	Begin Channel	Biken (Bikien) /pass/
Begin	Begin	Biken (Bikien)
Medyeron Channel	Medyeron Channel	Mejurwon (Majurwon) /pass/

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by F. R. Fosberg

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by Roy T. Tsuda

116. *Reef studies at Addu Atoll, Maldive Islands*
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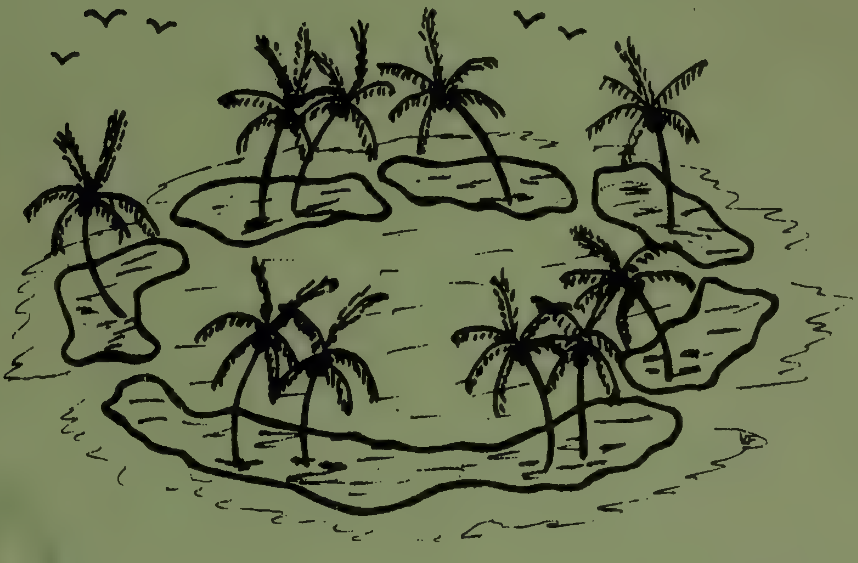
117. *Atoll News and Comment*



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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past nineteen years.

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Northern Marshall Islands land biota: birds

by

F. R. Fosberg

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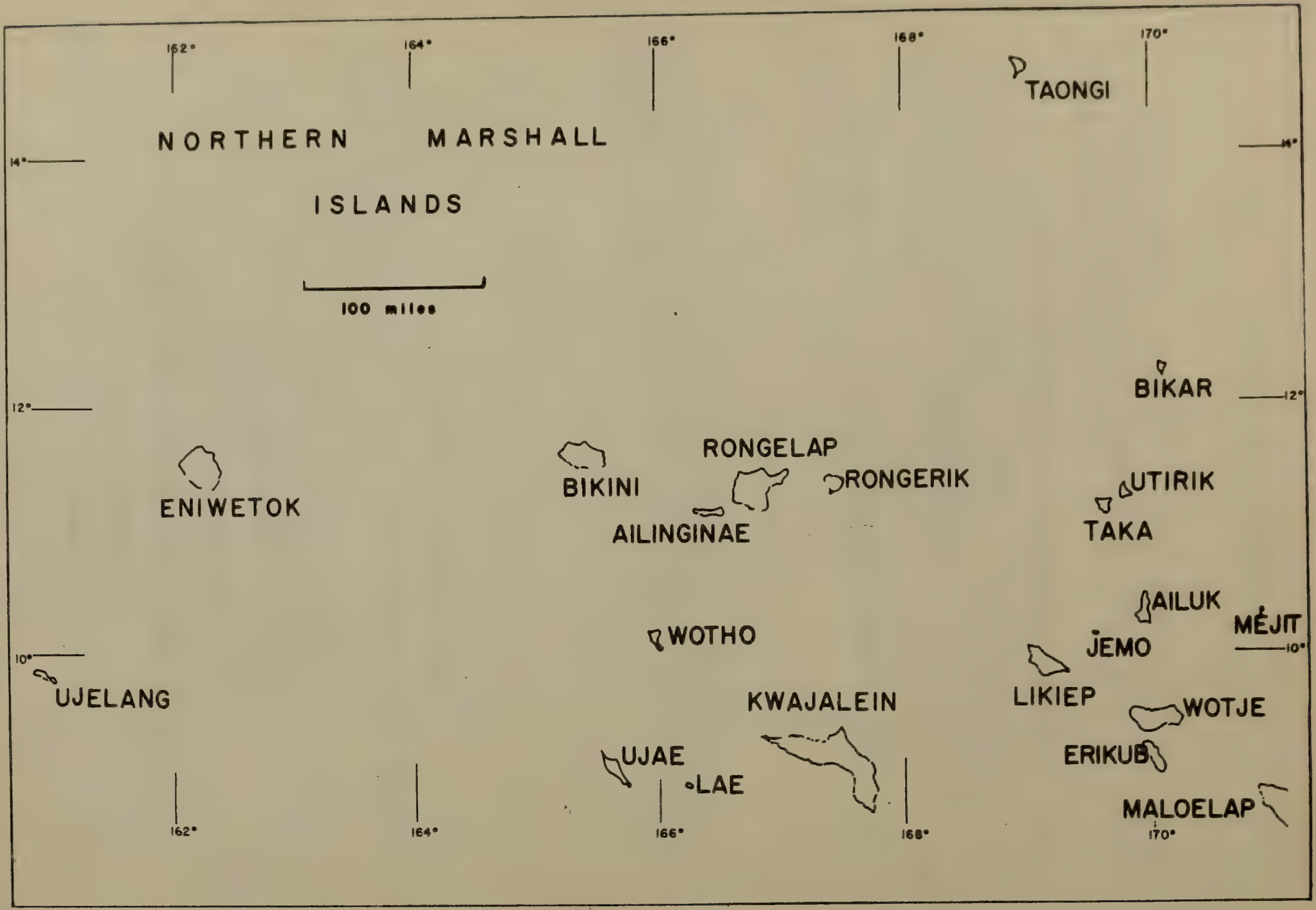
162°
164°
166°
168°
170°
TAONGI
14°
NORTHERN MARSHALL
ISLANDS
100 miles
BIKAR
12°
ENIWETOK
BIKINI
RONGELAP
RONGERIK
UTIRIK
TAKA
AILINGINAE
AILUK
MĖJIT
JEMO
WOTHO
10°
UJELANG
LIKIEP
KWAJALEIN
WOTJE
UJAE
LAE
ERIKUB
MALOELAP

FIGURE 1. MAP OF THE NORTHERN MARSHALL ISLANDS

Northern Marshall Islands Land Biota: Birds

by

F. R. Fosberg

Although ornithological observations have not been the main object of any phase of our work on the Northern Marshall Islands, numerous notes on birds have accumulated which are here placed on record. The birds were identified by use of Ernst Mayr's "Birds of the Southwest Pacific" and the names used here are mostly those accepted by Mayr in that work. Unfortunately it was impractical to document these records with specimens. The sight observations presented should therefore be accepted with some reservations.

The observations recorded here were mainly made on the U.S. Geological Survey expeditions to the Northern Marshalls in 1951 and 1952, when the author was a passenger on U. S. Army survey ships. Additional notes were made on Wake Island in 1953, 1961, and 1963, and in the Northern Marshalls in 1956, this time courtesy of the U. S. Naval Radiological Defense Laboratory, and on several briefer visits.

The atolls visited were Wake, Pokak, Bikar, Rongelap, Ailinginae, Rongerik, Taka, Utirik, Ailuk, Jemo, Likiep, Wotho, Ujelang, Ujae, Lae, and Kwajalein. Details of the 1951-1952 trips may be found in Atoll Research Bulletin 38: 1-36, 1955. No account of the later visits has been prepared, though lists of the land plants have been published as well as an account of what may have been fallout damage (ARB 61: 1-11, 1959).

Here will be given a very brief description of each atoll and its bird fauna, then a systematic list by species, with observation on occurrence, numbers, behavior, and anything else of interest under each one.

DESCRIPTION OF ATOLLS VISITED AND LISTS OF BIRDS SEEN

Wake Atoll

Wake Atoll (see ARB 66: 1-22, 1959, 67: 1-20, 1959) is semiarid in aspect, with pronounced dry seasons, and is largely wooded with low trees and shrubs. It undoubtedly supported very large bird colonies at one time, but, probably because of World War II, in 1951-52 there were relatively few birds. Rats were very abundant in the late 1940's and early 1950's but were almost eliminated by a poisoning campaign in 1952 by Mr. Fred Schultz. Whether they have multiplied again I do not know. A typhoon in 1952 caused widespread devastation to the vegetation and doubtless to the animal population. The island was visited October 22, 1951; April 19-21, 1952; July 18, 1952; October 22-23, 1953; September 8-13, 1961; and March 7-9, 1963. The following birds were seen:

TABLE I: Species recorded from various atolls and islands in the northern Marshall Islands during the present study.

	Ailinginae	Ailuk	Bikar	Jemo	Kwajalein	Lae	Likiep	Pokak	Rongelap	Rongerik	Taka	Ujae	Ujelang	Utirik	Wake	Wotho
Black-footed Albatross (offshore only)								X								
Wedge-tailed Shearwater								X								
White-tailed Tropicbird			X					X						X	X	
Red-tailed Tropicbird			X					X							X	
Masked Booby			X					X							X	
Brown Booby			X	X	X			X			X	X			X	X
Red-footed Booby			X	X				X?				X			X	
Great Frigatebird		X	X	X	X			X				X	X		X	X
Reef Heron		X			X	X	X	X				X	X			X
Pintail Duck															X	
Muscovy Duck													X	X		X
Chicken		X		X		X	X		X				X	X		X
Golden Plover		X	X	X	X	X	X	X	X			X	X	X	X	X
Ruddy Turnstone	X	X	X		X	X	X	X	X		X	X	X	X	X	X
Whimbrel					X	X						X		X		X
Bristle-thighed Curlew	X	X	X					X	X	X	X	X	X	X	X	X
Wandering Tattler			X		X	X		X		X		X	X	X	X	X
Bar-tailed Godwit (?)					X											
Black-naped Tern		X	X		X							X	X			X
Bridled Tern			X					X								
Sooty Tern		X	X		X			X			X		X		X	
Crested Tern			X		X	X		X				X	X	X		X
Blue-gray Noddy			X					X								
Common Noddy	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
White-capped Noddy	X	X	X	X	X	X		X	X		X	X	X			X
Fairy Tern	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
New Zealand Cuckoo							X									
Indian Mynah					X											
Java Sparrow															X	

1. *Phaethon lepturus*
2. *Phaethon rubricauda*
3. *Sula dactylatra*
4. *Sula leucogaster*
5. *Sula sula*
6. *Fregata minor*
7. *Anas acuta*
8. *Pluvialis dominica*
9. *Arenaria interpres*
10. *Numenius tahitiensis*
11. *Heteroscelus incanum*
12. *Sterna fuscata*
13. *Anous stolidus*
14. *Gygis alba*
15. *Padda oryzivora*

Pokak Atoll

Pokak Atoll is even more arid than Wake and has somewhat the same aspect, but with lower trees and far fewer species. Rats and lizards are common, but because the island has never been inhabited and presents landing difficulties, it is one of the finest sea bird rookeries in the central Pacific. When a ship whistle was sounded off Kamome Islet in 1951, the sky was literally blackened above the islet by the birds that flew up. These were probably mostly Sooty Terns, but many other species were also present. The atoll was visited November 25, 1961 (examined only from ship); March 25, 1952 (examined only from ship); and July 20-27, 1952. The week spent on this atoll in July 1952, by C. G. Johnson and me, was probably the first scientific investigation to be made there. Birds observed were:

1. *Diomedea nigripes* (offshore only)
2. *Puffinus pacificus*
3. *Phaethon lepturus*
4. *Phaethon rubricauda*
5. *Sula dactylatra*
6. *Sula leucogaster*
7. *Sula sula*
8. *Fregata minor*
9. *Demigretta sacra*
10. *Pluvialis dominica*
11. *Arenaria interpres*
12. *Numenius tahitiensis*
13. *Heteroscelus incanum*
14. *Sterna lunata*
15. *Sterna fuscata*
16. *Thalasseus bergii*
17. *Procelsterna cerulea*
18. *Anous stolidus*
19. *Anous tenuirostris*
20. *Gygis alba*

Bikar Atoll

This rather small atoll is almost undisturbed by man. The only obvious evidence of his presence is a small grove of coconuts on Bikar Islet, which is otherwise covered partly with dense *Pisonia* forest and partly with open scrub; one projecting rocky part is completely bare of vegetation. The other two islets of any size are also mostly covered by *Pisonia* forest, but have some open *Tournefortia* "orchard" and some herbaceous vegetation. A small sandbank, Jaborero Islet, has only a thin growth of *Portulaca*. The atoll was visited November 26, 1951 (examined only from ship); March 24, 1952 (examined only from ship); and August 6-11, 1952.

Birds are to be seen in great abundance--indeed this is one of the finest rookeries in the Marshalls, second only to Pokak. It is said to have been preserved as a bird sanctuary, protected by taboos, in pre-European times. Birds seen were:

1. *Phaethon lepturus*
2. *Phaethon rubricauda*
3. *Sula dactylatra*
4. *Sula leucogaster*
5. *Sula sula*
6. *Fregata minor*
7. *Pluvialis dominica*
8. *Arenaria interpres*
9. *Numenius tahitiensis*
10. *Heteroscelus incanum*
11. *Sterna sumatrana*
12. *Sterna lunata*
13. *Sterna fuscata*
14. *Thalasseus bergii*
15. *Procelsterna cerulea*
16. *Anous stolidus*
17. *Anous tenuirostris*
18. *Gygis alba*

Kwajalein Atoll

This is an enormous atoll, one of the largest in the world in total area. Its larger islets are among the most completely altered of all islands in the Pacific. It was the scene of heavy fighting in World War II and has been used as an American base ever since. Some of the smaller islets are still relatively undisturbed, and have been remarkably little explored considering how close they are to a major stopping place of trans-Pacific planes. Some of them, as seen from the air, have good native forest, though most are planted to coconuts or covered by installations of one sort or another. One islet, Enivetak, inside the lagoon rather than on the reef, is covered by magnificent *Pisonia* forest, perhaps the finest still to be found anywhere. Here are great numbers of birds. It is probable that this islet was reserved as a bird sanctuary in pre-European times, protected by taboos, and through some miracle, perhaps a lingering fear of the taboo, has remained in a virtually primitive condition.

The atoll was visited a number of times but with little opportunity for serious study; January 15-28, February 29 and March 15, 1952; February 2-12, 1956; and several briefer stops on other dates.

Considerable numbers of birds persist on the atoll, and a few of them have even accommodated themselves to the presence of men in great numbers. Here, also, is the only naturalized exotic bird in the Marshalls, the mynah. Species seen were:

1. *Sula leucogaster*
2. *Fregata minor*
3. *Demigretta sacra*
4. *Pluvialis dominica*
5. *Arenaria interpres*
6. *Numenius phaeopus*
7. *Heteroscelus incanum*
8. *Limosa lapponica* (?)
9. *Sterna sumatrana*
10. *Sterna fuscata*
11. *Thalasseus bergii*
12. *Anous stolidus*
13. *Anous tenuirostris*
14. *Gygis alba*
15. *Acridotheres tristis*

Rongelap Atoll

This is a large atoll, inhabited, but with conditions so severe that it is about on the limit of habitability by a self-contained culture. The large islets in the southern part, especially Rongelap Islet, are largely planted to coconuts. Those to the north are smaller and are still largely wooded or partly grassy, most of them having only a few coconuts, and many of these in poor condition or dead. *Pisonia* forest is still rather common on these islets. The poor condition of the vegetation of this atoll is described in ARB 61: 1-11, 1959. The atoll was visited February 7-9, 15, 1956. Very few birds were seen, both in species and actual numbers. Those seen were:

1. *Gallus gallus*
2. *Pluvialis dominica*
3. *Arenaria interpres*
4. *Numenius tahitiensis*
5. *Anous stolidus*
6. *Anous tenuirostris*
7. *Gygis alba*

Rongerik Atoll

A fair-sized atoll, elongate north and south, with the largest islet, Eniwetak, on the east reef, Rongerik has been shown to be just too severe an environment for present-day Marshallese habitation. It has not been inhabited in historic times, except when the Bikini people were moved there for a short time in 1946. This move was unsuccessful, and the people were soon removed. *Pisonia* and *Cordia* forests are common, but there has been much disturbance by construction crews in connection with weapons testing in Bikini and Enivetok. In 1956, the *Cordia* forest, especially showed severe dieback at the tips of the branchlets, 2 years after it had been heavily sprinkled with radioactive fallout. There was very little opportunity to study this atoll, only a short visit to Enivetak Islet on February 11, 1956 (see ARB 51). The very few birds in evidence included the following:

1. *Numenius tahitiensis*
2. *Heteroscelus incanum*
3. *Anous stolidus*
4. *Gygis alba*

Ailinginae Atoll

This is a rather small atoll, uninhabited, with one islet, Enibuk, largely planted to coconuts; the others are mostly wooded, several of them with small numbers of coconuts and some grassy land with scattered trees. There was doubtless an abundance of birds, but little opportunity was afforded to observe them. One short visit was made to Sifo Islet on February 10, 1956. Birds seen were:

1. *Arenaria interpres*
2. *Numenius tahitiensis*
3. *Anous stolidus*
4. *Anous tenuirostris*
5. *Gygis alba*

Taka Atoll

This is a small atoll, moderately dry, but able to support coconuts, which are planted on about one-third of the largest islet, Taka. The rest is covered by a scrub forest, in 1951 appearing quite battered by a recent typhoon. The atoll is uninhabited; hence birds are abundant, especially on the small brushy Watwerok Islet, which is, in its more open parts, a vast rookery of Sooty Terns. Lojiron is another small islet where there were abundant birds, especially *Gygis alba*, nesting in a small grove of *Pisonia* trees. The atoll was visited December 5-9, 1951. Birds seen were:

1. *Sula leucogaster*
2. *Arenaria interpres*
3. *Numenius tahitiensis*
4. *Sterna fuscata*
5. *Anous stolidus*
6. *Anous tenuirostris*
7. *Gygis alba*

Utirik Atoll

This populated atoll has one principal islet and four smaller ones. The larger islet, Utirik, is planted to coconuts, except for a long westward projection, which has been swept bare of vegetation and even of soil by typhoons, and a strip on the northeast side which has an enormous boulder ridge and some scrub forest and meadowlike open ground. Birds were not plentiful on Utirik Islet, but more so on Ealuk Islet, a small islet to the north, where the native scrub forest still exists. The atoll was visited November 23-December 4, 1951, and February 13, 1956. Not much time was spent in observation of birds on this atoll. Only the following were seen:

1. *Phaethon lepturus*
2. *Cairina moschata*
3. *Gallus gallus*
4. *Pluvialis dominica*
5. *Arenaria interpres*
6. *Numenius phaeopus*
7. *Numenius tahitiensis*
8. *Heteroscelus incanum*
9. *Thalasseus bergii*
10. *Gygis alba*

Likiep Atoll

This is a large atoll, almost completely planted to coconuts, and heavily populated. Our visits were December 11-18, 1951 and February 4 and 14, 1956. Little time was spent studying birds, which were not abundant on the islets visited. The species seen were:

1. *Demigretta sacra*
2. *Gallus gallus*
3. *Pluvialis dominca*
4. *Arenaria interpres*
5. *Anous stolidus*
6. *Gygis alba*
7. *Eudynamis taitensis*

Jemo Island

Jemo is a single small islet on a linear segment of reef. Although small, difficult to land on, and uninhabited, it has been mostly cleared and planted to coconuts. A strip of rather fine forest still remains along the south and west sides, part of it of huge *Pisonia grandis* trees. It was in this forest that the association between *Pisonia* trees, sea birds, and phosphate rock was first noticed, and a theory of atoll phosphate rock formation was first formulated. A part of the coconut plantation, that next to the *Pisonia* forest and growing on dark soil, is in luxuriant condition. This area was probably under *Pisonia* forest before clearing. The other half of the plantation was, in 1951, in poor condition indeed, with trees dying before they reached a great height. The soil here is pure coral sand. On the windward side of the island is a broad, noticeably wind-sheared fringe of *Scaevola taccada*. Birds were seen in some abundance, especially in the *Pisonia* forest. What looked like two owl pellets were being chewed by hermit crabs. Our visit was December 18-22, 1951. The birds seen were:

1. *Sula leucogaster*
2. *Sula sula*
3. *Fregata minor*
4. *Gallus gallus*
5. *Pluvialis dominica*
6. *Anous stolidus*
7. *Anous tenuirostris*
8. *Gygis alba*

Lae Atoll

This is a medium-sized, fairly wet atoll, populated, and with the largest islets planted to coconuts, but in 1951 some of the smaller islets were still covered at least partially by natural vegetation. *Pisonia* forest, *Ochrosia* forest, and mixed forest were well developed. Lae was visited January 6-10, 1952. Birds were fairly common, in spite of the presence of humans, though nowhere abundant. The species seen were:

1. *Demigretta sacra*
2. *Gallus gallus*
3. *Pluvialis dominica*
4. *Arenaria interpres*
5. *Numenius phaeopus*
6. *Heteroscelus incanum*
7. *Thalasseus bergii*
8. *Anous stolidus*
9. *Anous tenuirostris*
10. *Gygis alba*

Ujae Atoll

Ujae is a fairly wet atoll, elongate east and west, and has many islets; some of them had considerable native vegetation left in 1952, partly replaced by coconut plantation. Mixed forest, *Pisonia* forest, and *Ochrosia* forest are all well represented here. According to the people here, they eat all birds that they can catch except the Reef Heron. One method of catching birds was observed. A fire was built at the base of a huge *Pisonia* tree in which were many nests of the White-capped Noddy. This smouldered for a couple of days; then the tree crashed down. Young but fully feathered noddies were thrown from their nests in large numbers. They could not yet fly and were partly stunned. Five or six dozen birds were gathered up, their wings chopped off, and they were cooked. The atoll was visited February 16-23 and March 2-13, 1952. The following birds were seen:

1. *Sula leucogaster*
2. *Sula sula*
3. *Fregata minor*
4. *Demigretta sacra*
5. *Pluvialis dominica*
6. *Arenaria interpres*
7. *Numenius phaeopus*
8. *Numenius tahitiensis*
9. *Heteroscelus incanum*
10. *Sterna sumatrana*
11. *Thalasseus bergii*
12. *Anous stolidus*
13. *Anous tenuirostris*
14. *Gygis alba*

Ailuk Atoll

Ailuk is an elongate atoll extending north and south, with a great number of islets along its eastern reef and only one on the western side. The largest, Ailuk Islet, on the northern end, has a considerable population and is almost entirely planted to coconuts. Most of the smaller islets to the north have at least some coconuts, but many of them still retain at least a strip of native vegetation along their eastern, seaward sides, protecting the coconut trees from excessive wind. A few birds were seen on Ailuk Islet, many more on the smaller islets to the north. The atoll was visited December 24-31, 1951. The birds seen were:

1. *Fregata minor*
2. *Demigretta sacra*
3. *Gallus gallus*
4. *Pluvialis dominica*
5. *Arenaria interpres*
6. *Numenius tahitiensis*
7. *Sterna sumatrana*
8. *Sterna fuscata*
9. *Anous stolidus*
10. *Anous tenuirostris*
11. *Gygis alba*

Wotho Atoll

Among those of the northern Marshall Islands with fairly abundant rainfall, Wotho had in 1952 the smallest population and the largest area of native forest. In fact, it was possible here to gain some idea of what the original vegetation of these islands may have been like. Even the larger islets had only been partly cleared and planted to coconuts. *Ochrosia* forest, possibly the climax vegetation of atolls in this rainfall belt, covered a larger area here than in any other atoll visited. Some *Pisonia* forest and large areas of mixed forest were found. Coconut crabs, *Birgus latro*, were more common here than any other place where they were seen. The atoll was visited February 12-16 and March 18-22, 1952. Birds observed were:

1. *Sula leucogaster*
2. *Fregata minor*
3. *Demigretta sacra*
4. *Cairina moschata*
5. *Gallus gallus*
6. *Pluvialis dominica*
7. *Arenaria interpres*
8. *Numenius phaeopus*
9. *Numenius tahitiensis*
10. *Heteroscelus incanum*
11. *Sterna sumatrana*
12. *Thalasseus bergii*
13. *Anous stolidus*
14. *Anous tenuirostris*
15. *Gygis alba*

Ujelang Atoll

The westernmost of the Marshall group, sometimes regarded as one of the Caroline Islands, Ujelang, elongate in an east-west direction, has a considerable number of islets, most of which had some vegetation in 1952. The large Ujelang Islet was planted to coconuts during the German administration. For many years this atoll had no population except plantation laborers, but in 1947 the people of Eniwetok were moved there to make way for the testing of atomic weapons. Birds were, in 1952, generally abundant, especially on islets other than Ujelang itself. The atoll was visited February 5-8, 1952. The following species were observed on this atoll:

1. *Fregata minor*
2. *Demigretta sacra*
3. *Cairina moschata*
4. *Gallus gallus*
5. *Pluvialis dominica*
6. *Arenaria interpres*
7. *Numenius tahitiensis*
8. *Heteroscelus incanum*
9. *Sterna sumatrana*
10. *Sterna fuscata*
11. *Thalasseus bergii*
12. *Anous stolidus*
13. *Anous tenuirostris*
14. *Gygis alba*

ACCOUNT OF BIRDS BY SPECIES

Diomedea nigripes — Black-footed Albatross

What was probably the Black-footed Albatross was seen on two occasions flying near Pokak Atoll. On November 25, 1951, a single albatross flew by the ship off this atoll during the morning. On our next visit, March 25, 1952, Charles Frey, engineer, reported seeing a Black-footed Albatross flying near the atoll on our arrival early in the morning. None were seen actually on the islets, or flying nearby during our longer July visit.

Puffinus pacificus — Wedge-tailed Shearwater

Shearwaters were seen at various times at sea, but could not be identified with any confidence. However, on Pokak Atoll, a short distance inland from the lagoon shore of Sibylla, Breje, Kamome, and North Islets, there is an extensive series of rookeries of what seem to be Wedge-tailed Shearwaters, though even with the bird in hand it could not be made to fit, exactly, any of the descriptions in either Mayr's "Birds of the Southwest Pacific" or Alexander's "Birds of the Ocean."

These birds nest in burrows that go straight down about a foot, then horizontally for the same distance or more. The roofs often give way when stepped on. In fact, walking over these sandy areas resulted in caving in a burrow every few steps. The burrows are very abundant wherever the soil is sandy, as close as 3 feet apart. The mouths are marked by low, wide accumulations of sand that is whiter than the general ground color. This results in a most peculiar appearance on air photos of closely spaced white dots. Where there is too much rubble in the soil or the sand is too shallow, the burrows are merely slight depressions concealed by tufts of grass bent over them.

One adult bird stays in the burrow during the day. The other returns and takes its place at dusk. The burrows contained, at the time of our visit, eggs or nearly grown young in various stages of feathering out, up to those almost ready to fly. When the brooding adult bird is either pulled or frightened from a burrow, the egg is often clasped between the feet and is broken when the bird emerges. The egg is white. When the bird is frightened from the burrow, it flutters across the ground before taking flight.

The birds are seen flying near the atoll in small flocks or singly, but not far out at sea.

It was hard to estimate the numbers of these birds, but there must have been many tens of thousands. It is quite possible that other shearwaters or petrels were present, as some of those seen flying at sea were noticeably smaller, but all seen nesting were the same kind and size.

Phaethon lepturus   White-tailed Tropicbird or Bos'n bird

This beautiful bird is not at all common in the northern Marshalls. One was seen flying on Wake Islet, Wake Atoll, near Flipper Point, September 1961 (Sachet), and two were seen flying on Wilkes Islet, Wake Atoll, on March 8, 1963. One was seen flying at sea one-third of the way from Wake to Pokak Atoll on July 15, 1952. Another was seen flying over the seaward side of Sibylla Islet, Pokak, several days later. One was seen flying over the lagoon of Utirik Atoll on December 4, 1951. In the interior of Bikar Islet, Bikar Atoll, in openings in dense Pisonia forest 3 or 4 were seen at a time, flying round and round, making harsh protesting noises. Finally a nest was located about 7 meters up, in a hole in a large Pisonia tree. This could not be reached with the equipment at hand, but birds were seen to enter the hole.

Phaethon rubricauda   Red-tailed Tropicbird

Red-tailed Tropicbirds were only observed on Wake, Pokak, and Bikar.

On Wilkes Islet, Wake Atoll, two were seen flying on March 8, 1963. They were pure satiny white with a red mark near the eye, and black feet visible along body when flying (Sachet).

On Pokak Atoll they were seen fairly commonly, flying over all the islets during the week of July 20-27, 1952. They were nesting in small numbers and incubating eggs on all islets except those west of Sibylla. They are extremely tenacious at guarding their eggs. They scream at anyone who approaches but will not leave their eggs, even when their red spike-like tail feathers are rudely pulled out. The eggs are laid on gravel or sand in open brush. A few almost grown young were seen. They have black-and-white barred feathers on wings and back, similar to the markings on a barred-rock chicken. Their beaks are black at this stage but red in the adult birds.

On Bikar Atoll, during the week of August 7-11, 1952, small groups of several to a dozen birds were often seen flying, especially over the north end of Bikar Islet. Here they would fly round and round, making harsh noises. What this was about was not evident. Possibly they wanted to use this area as a nesting site but were disturbed by our camp.

One of the attractive features of the Red-tailed Tropicbird is the roseate sheen to the white parts of the plumage that can be seen as they sit on their eggs.

Sula dactylatra   Masked, or Blue-faced Booby

This was the least frequently observed booby on the atolls visited and was seen only on Wake, Pokak, and Bikar. It was seen mostly on the ground, either nesting or resting. Its beak, here, was a dull yellow, shading to dull bluish or greenish at the base. The young are very white and have deep down that makes them look like animated balls of cotton. On Wake Atoll, October 22-23, 1953, a very few were seen flying with frigatebirds and Brown Boobies over Peale Islet. In the sea around Pokak Atoll, Masked Boobies were observed flying and fishing with both other kinds on March 25, 1952, in small numbers. In July, these birds were seen singly or in pairs almost anywhere on the atoll except South Islet, always sitting on the ground or flying. They apparently fish at least partly during the day, as they were seen fishing on March 25, and in July one was observed to arrive and feed her young in the early evening before sundown.

On Bikar Atoll, March 24, 1952, a few were seen fishing with both other boobies, noddies, and Fairy Terns. In August (7-11) small numbers were resting on the ground, especially on the seaward sides of the islets, particularly Jaliklik. There were quite a few young in all stages of development. The old birds are very stubborn about leaving the young. They nest on the ground, using practically no nesting material at all.

Sula leucogaster Brown Booby

This is the most common of the boobies, generally, and was seen on more atolls than the others, but was not seen nesting except on Wake Island, where it nested on the ground. It was most often seen flying, either going and coming from land, or fishing.

Near Pokak Atoll on March 25, 1952, large numbers of Brown Boobies followed the ship, diving at trailing fish lures. Several were caught. They were seen fishing with Masked Boobies. In July also many Brown Boobies were seen. It was hard to get an idea of their numbers and behavior as their habits seemed almost the opposite of those of the Red-footed Booby. During the day most of them were seen flying, especially over seaward beaches and reefs. They seemed to be the favorite victims of piracy by frigatebirds. When seen sitting, they were practically always on the ground or on rocks.

On Bikar Atoll, March 24, 1952, they were seen commonly, flying about, especially around seaward beaches, and fishing in company with both other boobies as well as noddies and Fairy Terns. Three of them made passes at the flag fluttering at the masthead. On August 7-11, many were seen flying and resting on trees on low branches and stubs, as well as on the ground. None were seen nesting, although several times birds behaved as though trying to draw attention of intruders away from nests. One bird was frightened off a nest about 4 meters up in a Pisonia tree, but identification was not certain, and it may well have been a dark phase of the Red-footed Booby. The color of the backs of these birds is a dark sooty-brown, rather than chocolate-brown as described by Mayr.

On Jemo Island, one Brown Booby was positively identified flying, December 20, 1951. On Kwajalein, also, one was seen flying with frigatebirds on January 23, 1952. Three were seen flying over the lagoon at Taka at 8:30 a.m., December 7, 1951. At Wotho Atoll, one was seen at Biken Islet, one at Ombelim Islet, and an immature one at sea in March, 1952. On Ujae, about 30 were seen on the evening of March 1, 1952, returning to Bokerok Islet after a day's fishing. One each was seen on Bikenkar and Ujae islets (by T. Arnow).

On Wake Island, October 22-25, 1953, a few were seen flying with frigatebirds on Peale Islet. On March 9, 1963, about 20 pairs of Brown Boobies were nesting along the lagoon side of Kuku Point, on the ground just back of the shore in the low vegetation. All had young, either in the downy condition or with wings somewhat feathered out. The adult plumage was dark reddish-sooty brown on the back.

Sula sula Red-footed Booby

Red-footed Boobies were seen in numbers on the uninhabited northern atolls, but scarcely at all on the inhabited ones. This is to be expected, as their nests are commonly in low trees, readily accessible to the Marshallese, who eat sea birds of all sorts. The white plumage, bright-red feet, and blue beak readily identify these birds in the adult stage, but identification of immature ones is much less certain.

On our first visit to Pokak on November 25, 1951, many boobies were seen, but not distinguished as to species. On March 25, 1952, Red-footed Boobies were definitely seen, fishing offshore in company with Brown and Masked Boobies. In July (20-27), 1952, large numbers were seen on Pokak. The Red-footed seemed to be the most common boobies on the atoll, at least during the daytime. They were found scattered, roosting in the trees in all parts of the islets where Tournefortia or Pisonia trees occur, but were less common on Pokak Islet than elsewhere. During the day they were seen much more often sitting in the trees than flying, so it may be that they do most of their fishing at night. Judging from the guano accumulations, each bird must have a particular branch that is his favorite roosting place. They do not seem to be gregarious in the sense that they congregate in groups. They may be approached closely, only attempting to fly when actually molested or, sometimes, when a person is within a few feet. One, when disturbed, disgorged half a dozen fair-sized squid. A very few young birds were seen, and one bird was incubating an egg on a nest in a tree.

On our first visit to Bikar, on November 26, 1951, several Red-footed Boobies were seen flying. On March 24, 1952, considerable numbers were seen near the atoll, fishing with both other species of boobies, noddies, and Fairy Terns. Many were roosting in trees. During the period August 7-11, large numbers were to be seen at almost any time of day, roosting in Pisonia trees, or flying about when disturbed. A few nests were spotted, usually high in Pisonia trees, with old birds sitting on them, or with almost mature young.

On Jemo Island, Red-footed Boobies were nesting in numbers in the Pisonia trees, contributing greatly to the formation of phosphate rock beneath.

On Ujae Atoll, a single dead Red-footed Booby was seen on the outer beach of Rua Islet on February 25, 1952. On Wake Island a few were seen nesting on Peale Islet, April 21, and one flying on July 18.

Nests were seen in September 1961 (Sachet) with well-grown young in *Tournefortia* forest back of Kuku Point, Wilkes Islet, Wake Atoll, and at the same place in March 1963 about 10 or 12 nests were seen, mostly with full-grown young, wings fully feathered out. The nests were in the same trees as those of frigatebirds. Birds were sitting on several nests which may have contained eggs, but the eggs were not visible from below.

Fregata minor Great Frigatebird or Man-o'-War Bird

This is one of the most magnificent of sea birds and a characteristic sight in the air over many atolls. They soar for hours, often in one place, apparently for the sheer joy of it. During storms their soaring ability is shown off to the best advantage, when they seem to be playing in the wind.

The amount and distribution of white on the females and young birds vary a great deal, and all attempts to perceive a regular pattern failed. The mature males are entirely black, except for their scarlet inflatable pouches.

The Marshallese name for the frigatebird is "aak" (Ujae, Ujelang).

On November 25, 1951, many frigatebirds were seen flying around Pokak Atoll, as many as 25 at a time. On March 25, 1952, 8 or 10 followed the ship and fished with the boobies. In July (20-27) an enormous population of frigatebirds were nesting here. The nests are in *Tournefortia* trees, and are small for the size of the birds, usually not more than 2 dm across. On a foundation of a few twigs, the nest is built entirely of the dried stems of *Ipomoea tuba*. It is soon cemented into a sturdy flattish structure by the accumulation of guano after the young bird hatches. At the time of our visit there were eggs and young in all stages of development. The partly grown young have blackish feathers on wings and back and white downy breast, neck, and head. The heads of immature birds vary from definitely rust colored to white. Both males and females sit on the eggs.

Nests are scattered over all except South Islet but are most numerous on Sibylla and Breje Islets, with many also on the wooded part of Kamome. They seem not to be especially concentrated in any one or few restricted spots, but to be fairly generally distributed where there are suitable trees. When approached the young rattle their bills furiously and scream at the intruder. Older birds usually fly away when an intruder gets to within a few feet, but occasionally they will disgorge fish first.

When a small boat crossed the lagoon and made a landing on Sibylla Islet hundreds of these birds were in the air at once circling over it. Normally at any time of the day there were a few in the air. Occasionally they would snatch fish from the surface of the water, and now and then, especially toward evening, it was possible to watch them pursuing boobies to pirate their day's catch of fish. It is a rare sight to watch these superb fliers in an aerial contest. Contrary to the general opinion, it was observed that the boobies often escaped without disgorging their fish.

On Ailuk, December 26-27, 1951, a single frigatebird was seen flying between Eneao and Micnwa Islets, two over Baojen Islet, and one over Enenkonge Islet.

On Jemo, December 15, 1951, at least 15 were seen flying at one time.

On November 26, while approaching Bikar Atoll, we were met by 6 frigatebirds. On March 24, 1952, many were roosting in the trees, scared up in great swarms by blasts of the ship's whistle. During the period August 7-11, they were seen in large numbers, roosting in trees and flying over the atoll. A few immature ones were seen in Pisonia trees.

On January 19, 1952, one frigatebird was seen soaring over Kwajalein Islet, Kwajalein Atoll; many dozens on January 23, 1952, and two on February 2, 1956.

On Ujelang, February 3-8, 1952, very few were seen during the day. A few were seen over the smaller islets occasionally, especially late in the afternoon. On Kalo Islet, one afternoon at about 5 p.m., during a storm, four were seen calmly riding out the storm high in the air. They were joined by two, then two others, then two more coming in from the south. They sailed in one position above the islet for some time, apparently enjoying the situation, then glided off to the east. Their places were taken a few minutes later by four more. One day just before dark, 40-50 were seen on Pyokin Islet where they apparently roost.

A colony of at least 75 frigatebirds lived on Bokerok, a tiny islet south of Bock Channel, Ujae Atoll, in February and March 1952, where some could be seen in the Pisonia trees at almost any time. At sunset they soar in great numbers over Bock Channel.

On Wotho, a colony of well over 100 roosted on Ombelim Islet in February 1952. During the hot part of the day they usually rested. Toward evening they soared in great numbers over this and other islets, especially Biken, and out over the sea.

On Wake Atoll, Wake Islet supports a colony of considerable size. In April (20-21), 1952, many were seen mostly roosting on the remains of an old pier on Peale Islet, and quite a number were seen flying on July 18. On October 22-23, hundreds were seen flying and roosting on a great steel framework of a bombed-out Japanese building on Peale Islet and also on power lines. They were seen in numbers in September 1961 in the trees at the base of Flipper Point, Peale Islet (Sachet). They were nesting in trees on Wilkes Islet, just back of Kuku Point, in March 1963. Perhaps 10 or 12 pairs were seen with eggs or soaring with red pouches inflated. Some were carrying twigs for nests.

Demigretta sacra Reef Heron

The Reef Heron, though not abundant, is a common sight throughout the northern Marshall Islands; it was not seen on Wake Island. This is a medium-sized heron, and may be seen almost anywhere, in the woods or plantations, in openings, at the edge of the forest above the beach, around ponds and depressions, and out on the reef, standing very still or stalking its prey. It is called by the Marshallese "kaga" or "aga" (Ujelang) or "kawij" or "kavij" (Ujae), and, according to Enti, Chief of Ujae, is the only bird not eaten by them. When asked the reason for this he said, "It eats rats." It was not clear whether this habit made the bird unpalatable, or whether this was regarded as a beneficial service for which it was spared. Two color phases are almost equally common, a dark blue-gray one and a white one, with various intermediates, the most common being white variously mottled with gray. A single lighter gray (not bluish) one was seen on Lae, one of this color but with distal third of wings white, on Ujelang; and a white one with distal half of wings dark on Kwajalein. As this species seems to inhabit the islands the year around there seems to be no reason for detailing sightings by date. They are presented in Table II by atolls and islets and arranged by color phase and numbers seen.

Anas acuta Pintail Duck

One Pintail Duck was swimming in the pond in the angle of the runways on Wake Islet, Wake Atoll, on March 8, 1963. A local informant says that as many as 9 ducks have been seen here at one time. The subspecies was not determined.

Cairina moschata Muscovy Duck

A few domestic ducks, all of the muscovy type, were seen, either tethered or free in yards with the chickens. They were recorded from Ujelang, Utirik, and Wotho.

Gallus gallus Chicken

Chickens are found on all or most inhabited islands in the Marshalls, and even on some at least temporarily uninhabited ones. During the present surveys they were definitely recorded from Ailuk, Jemo, Lae, Likiep, Rongelap, Ujelang, Utirik, and Wotho, and were doubtless present on at least two of the others. Most seen were of a rather nondescript or mongrel type, somewhat resembling wild jungle fowl, but some resembling Plymouth Rock and other domestic breeds were also seen. They are generally allowed to run free. It is of interest that chickens were in the Marshalls in pre-European times, but were prized by the Marshallese for their feathers and very rarely used as food (Chamisso, A. von, Remarks and Opinions, p. 157, 1821; Grundemann, D., Deutsche Kolon. Zeit. 4:444, 1887).

TABLE II: Color phases of the Reef Heron in the northern Marshall Islands.

Atoll Islet: Date	Blue	Gray	Gray with distal wing tips white	Mottled	White with wing tips dark	White
Ailuk						
Akulwe (12/26/51)	1			1		
Jabbwi				X		X
Enenkong						X
Eneljar						X
Ulika				X		
I. north of Baojen	X					
Kwajalein						
Lojjairong (1/15/52) Lojjairek	1			2		2
Enebuoj (1/19/52)				1		1
Ebeye (1/26/52)					1	1
Kwajalein (1/27/52)	1					1
(3/15/52)	1					
Enelakken (8/3/52)	1			1		1
Lae (1/5-10/52)						
Lae	6	1		3		3
Loj	1					
Bikenaj						1
Bwi				1		
Lweljap	1					
Enejelto	1					
Rama	2					
Likiep						
Lado						1
Pokak (7/20-27/52)	3			3		4
Leeward reef (3/25/52)						2
Ujae (2/15-23/52 (3/2-15/52)						
Bock	1					1
Ujae	3					2
Ebeju	4					2
Wojia						1
Enelamoj	1					
Bik						1
Bikenkar						1
Ujelang (2/3-8/52)						
Kiloken				1		2
Ujelang	5		1	4		2
Morina						3
Kalo				1		
Wotho Atoll (2/15/52)	1					3

X - Present but numbers not recorded.

Pluvialis dominica Golden Plover

The Golden Plover may undoubtedly be seen at times on any island in the central Pacific, especially in winter when it migrates south from its Arctic or Subarctic breeding grounds. It seems probable, however, that some individuals fail to go north, as at least a few birds may be seen in the Marshalls even in August. They are walking or standing on reefs, beaches, village streets, airport runways, in grassy openings, and even under coconut trees. They are often observed walking and feeding with domestic chickens, and are then more easily approached than usual. The Marshallese name is "kolej" (Ailuk, Lae, Ujelang, Wotho), apparently a cognate of the Hawaiian "koleo."

On Ailuk Atoll, December 24-31, 1951, plovers were seen on almost all islets visited, common in open coconut groves, in openings, and at low tide on reefs. They were relatively tame, easily approached to within 15 meters, even closer when they were walking with chickens. On Jemo Island, December 18-22, 1951, only 2 were seen, possibly 2 sightings of the same individual. One was seen on Gejen Islet, Rongelap Atoll, on February 15, 1956. On Likiep, December 15-16, 1951, they were occasionally seen; a flock of 4 was on the reef flat at low tide. On Utirik, December 4, 1951, they were seen generally on all islets. They were very tame here, running with chickens, only flying up on close approach of a person. A number were also seen on Utirik Islet on February 13, 1956.

Plovers were especially common on Kwajalein, on Kwajalein Islet, where they may practically always be seen resting on the asphalt of the airstrips in flocks of up to 20, or even more. They seem very accustomed to people. Twelve were seen on January 15, 1952, on a lagoon debris flat; on January 19, a number were on both outer reef flat and inner beach; and on January 23, February 12 and 29, and August 3, they were seen in some numbers on the airstrip. Even in August, 5 were seen together there. On October 10, 1960, they were common generally on Kwajalein Islet, and a number were resting on the airstrip.

On Ujae Atoll plovers were not as common as on some atolls. During visits on February 16-21 and March 2-11, 1952, 2 were seen on the reef flat at the north end of Bock Islet, one on Rua Islet, and on Ebeju Islet, one was seen in a flock of turnstones on the lagoon beach, 6 in a flock on the seaward beach; 4 in a flock with turnstones and curlews on Wojia Islet on the reef flat; 2 on the north end of Enelamoj Islet, 4 in a flock with curlews on Alle Islet, and one each was seen on south and east beaches of Ujae Islet.

On Lae, January 6-10, 1952, plovers were seen generally in small numbers, up to 4 at a time, on beaches and reefs at low tide, in openings in woods, and in open coconut groves. They were less common on Ujelang than on most other atolls. Four were seen on the seaward reef of Boken Islet and four on the lagoon side of Ujelang Islet, February 3-8, 1952.

On Wotho Atoll, February 15, 1952, several plovers were seen with turnstones on beaches, in small openings in coconut groves, and around the village. During two visits, February 12-16 and March 18-22, 1952, they were seen in small numbers on inner and outer beaches and in the interior of most islets wherever conditions were at all open, often with turnstones, tattlers, and curlews.

On Bikar, August 6-11, 1952, single individuals, and rarely, small flocks of up to 7 birds, were commonly seen on all the islets, especially around the edges, on beaches and reef flats. On Pokak, July 20-27, plovers were seen now and then, one to three at a time, on any open space. They were mainly in winter plumage, mottled golden and dark above, white beneath. Five individuals were seen however, 3 at one time (by C. G. Johnson) in the handsome "spring plumage," dark brown beneath, with prominent white eyebrows and a white line running along the sides below the wings.

On Wake Atoll, October 23, 1951, and on October 22-23, 1953, several dozen were feeding around ponds and a few were scattered elsewhere. Two were seen on April 20, 1952, but Fred Schultz said that many were present only the day before. On March 8, 1963, 15 to 20 were seen on the shore of the pond in the angle formed by the runways on Wake Islet, and on March 7, 34 plovers were seen on the water catchment area.

Arenaria interpres Ruddy Turnstone

The Ruddy Turnstone is, next to the Fairy Tern, the most universally present bird in the northern Marshalls. It was seen on all the islands visited except on Jemo and Rongerik, and on the latter there would have been little opportunity to see it even had it been there. It was found singly, or more often in small flocks of 2 to a dozen or more individuals, usually busily searching along the beaches or reef flats at low tide. As seen in the Marshalls, it does not merit the adjective ruddy at all, as it shows black gray and white, with a conspicuous white rump and wingbars when it flies. When approached it usually flies up and along the beach 100 meters or so and settles down. The Marshallese name is "kut kut" or "kutekut" (Ujae, Ujelang).

On Wake Atoll, one was seen on October 23, 1953, and on March 8, 1963, a flock of 15 to 20 was seen on the shores of the pond in the angle of the runways. On Pokak Atoll, July 20-27, 1952, a few were seen along seaward beaches, usually in twos or threes, sometimes in association with tattlers and plovers. Single individuals, pairs, and small flocks of up to half a dozen were occasionally seen on beaches, reef flats, and rock flats on Bikar Atoll, August 6-11. One was seen in a tiny opening, well within the Pisonia forest on Bikar Islet. One was seen flying about 40 miles southwest of Bikar at 11:15 a.m., August 13.

A small flock was seen on the west end of Watwerok Islet, Taka Atoll, on December 9, 1951. On Ailuk, December 24-31, 3 were seen on Akulwe Islet on the outer beach, a flock of 15 on the lagoon reef flat, Ailuk Islet, at low tide, and a few on each of Marib and Barjen Islets. On Likiep Islet, Likiep Atoll, several small flocks, one of them of 21 birds, were seen on December 16, 1951. On Kwajalein Islet, Kwajalein Atoll, October 19, 1960, a considerable flock of turnstones was seen on the airstrips. On Lae Atoll, January 7-10, 1952, 2 were seen on the outer beach of Loj, and one on Bikelabet Islet. On *Ujae*, February 16-25 and March 2-15, 1952, 5 were seen in a flock on the outer reef of Bock Islet; a flock of 7 or 8 was seen by Ted Arnow, and one of 5 was seen by Fosberg on Ujae Islet, outer reef; 4 were seen on Rua Islet, one in a grassy opening in the interior; a flock of 10 was on the lagoon beach and one of 5 on the seaward reef flat, Ebeju Islet; a flock of 7, with plovers and curlews was on the outer reef flat on Wojia Islet.

On *Ujelang Atoll*, February 3-8, 1952, a flock of 11 was seen on the seaward reef of Enimoni Islet, 2 on the lagoon beach of Enellap Islet, 8-10 on the seaward reef and passage beach of Bokan Islet, 7 on a sand flat in the west passage on Kiloken Islet, and on Ujelang Islet, 9 on the lagoon beach and a large flock was on the seaward reef flat. On *Wotho Atoll*, small flocks of 2 to 5 were seen on most islets on beaches or reef flats, often with plovers and tattlers, February 12-16, 1952. On February 7, 1956, 3 were seen on the seaward beach of Rongelap Islet, *Rongelap Atoll*, and toward evening 2 were flying over the lagoon. A few were seen on Sifo Islet, *Ailinginae*, on February 10, 1956. Eight were seen on the south beach of Utirik Islet, *Utirik Atoll*, and another flock on the open part of the long west spit of this islet, back of the lagoon beach ridge, February 13, 1956.

Numenius phaeopus Whimbrel

I found the Whimbrel to be very difficult to distinguish with confidence from the Bristle-thighed Curlew. What I took to be Whimbrels were brown birds with no rufous cast and with no chestnut on rump, that appeared, when flying, to be slightly shorter, stockier, with a somewhat more curved beak, rougher flight, and with a rather distinct note when flying: "dee-dee-dee-dee-dee."

Such were seen flying, one on *Wotho*, Enearik Islet, on March 20, 1952, one on *Utirik Atoll* in the interior of the long southwest spit on Utirik Islet, on February 13, 1956, and two on *Lae Atoll*, one by Arnow, one by me, January 6-10, 1952. Two were seen on *Ujae Atoll*, Ujae Islet, separately, possibly the same individual; one was seen on Rua Islet, and two were seen on the reef seaward on Ebeju Islet, March 2-15, 1952. Two curlews, Whimbrels judging from their notes, were seen on the Kwajalein airstrip in the sun at 3:15 p.m., October 19, 1960.

Numenius tahitiensis Bristle-thighed Curlew

These large shore birds are fairly common in the northern Marshalls and were seen on most of the atolls visited. Their note when flying is "kiwee, kiwee." They are seen in the interior of brushy islets as well as on the shores and reefs, and they must eat *Scaevola* fruits, among other things, as their droppings are often seen to be packed with *Scaevola* stones. They are called by the Marshallese "Kowak" (*Ujae*) or "Kuwak" (*Ujelang*, two informants).

One was seen on Taka Islet, Taka Atoll, on December 7, 1951, and one (December 26) on Ailuk on the seaward denuded area of Enejela Islet at low tide where it would not flush but kept walking ahead of me, keeping a distance of about 15 meters. Two were seen on Sifo Islet, Ailinginae, February 10, 1956; one on Eniwetak Islet, Rongerik, February 11; and one on the east shore of Gegen Islet, Rongelap Atoll, February 15. The last bird was very tame. On February 13, 1956, three were seen in the interior of the spit on the west end of Utirik Islet, Utirik Atoll.

On Ujae Atoll they were common, February 16-21 and March 2-11, 1952. Two or three could be seen at almost any time on Bock Islet, probably the same ones. They were usually walking around the outside of the islet, but one was in a rocky opening in *Scaevola* scrub; 4 or 5 were seen several times on Rua Islet, 2 on the seaward reef of Ebeju Islet, 2 on Wojia, with plovers and turnstones, one on Enelamoj Islet, 5 on the south passage beach, Bikenka Islet, and several, one with plovers, on Alle Islet. On Ujelang Atoll, February 3-8, 1952, one was seen on Jerko Islet, 3 on the seaward reef of Enimoni Islet, 3 on Kirinyan Islet on seaward reef, one was on lagoon side, one was on Morina Islet, and or 6 on Kiloken Islet, on the seaward reef, the passages, and in grassy openings in the scrub.

On Wotho, February 12-16 and March 18-22, 1952, they were commonly seen, singly, in pairs, or 3 or 4 together, on the beaches and reef flats of most of the islets. Here they were quite tame, allowing one to approach to within 3 to 5 meters before flying.

On Wake Island, one was seen in September 1961 near a little inlet on the lagoon side of the south arm of Wake Islet (Sachet). On March 7-9, 1963, several were seen near the pond in the angle of the runways on Wake Islet, and several were heard on Peale Islet. The cry was heard as "ti-tehi ti-rwhi" (Sachet). On Pokak Atoll, July 20-27, 1952, Bristle-thighed Curlews were seen more commonly than on any of the atolls visited. They were mostly on Sibylla, Breje, and Kamome Islets, 2 to 5 seen at a time. One morning at 7 o'clock a flock of 15 flew over our camp on Sibylla Islet at a rather low altitude. They were generally very tame. One pair, on Kamome, picked around on the beach to within 3 meters of where I was sitting. Another group of 5 spent a half hour aimlessly wandering around within 15 meters of where I was eating lunch, also on the lagoon shore of Kamome. They did not seem to be eating anything. One was panting, with its bill somewhat open and quivering; the day was very hot. Single individuals, two, or three at a time, were commonly seen on Bikar Atoll, August 6-11, 1952, on rock flats and around beaches. They were quite tame, allowing one to approach to within 10 meters before walking or flying away.

Heteroscelus incanum Wandering Tattler

This is a trim, dark gray bird, white beneath, seen on many islands but seldom more than 4 at a time, almost always on the reef flats or beaches, mostly on the seaward sides of the islets. They are somewhat more wary than the other shore birds, flying up when approached, circling out over the water or reef flat at low altitude and back, alighting 100 meters or more away along the shore. When they fly up, they sound a rather rapid high note "dee dee dee dee...." The Marshallese name is "kirij" (Ujae). Which subspecies was seen was never determined. All looked very uniform, except one smaller bird on Pokak Atoll.

On Kwajalein, January 15, 1952, several were seen on the outer reef flat; January 19, 8 were seen at once, and others before and after, at low tide on the outer beach; two were seen near the outer beach on February 2, 1956. On Lae, January 6-10, 1952, a few were seen, no more than 2 on an islet, usually on the outer beach or reef flat. They were seen on a number of islets on Ujae Atoll, February 16-23 and March 2-11, 1952, usually on exposed reef or rubble flats on the seaward side. On Bock Islet, 4 were seen in a flock on the outer reef flat, 2 together on a rubble flat on the lagoon side; and one to 3 were seen on each of Ujae, Rua, Ebeju, Alle, Bikenkar, and Enelamoj Islets. On Enelamoj, they were in a flock with turnstones. They usually flew low over the reef or the sea just outside it. On Wotho Atoll, February 12-16 and March 18-22, 1952, one or two were seen at a time, usually on outer beaches, reef flats, or passage beaches, on most islets, often in company with plovers or turnstones, or, more rarely, curlews. Seven were seen in a flock on February 9 on outer reef flats at Ujelang Atoll.

On Bikar Atoll 1 to 3 or rarely 4 Wandering Tattlers were occasionally seen on beaches and reef flats, especially on seaward sides of islets. They were commonly seen, as many as 4 at a time, July 20-27, 1952, in the passages and reef flats of Pokak Atoll. On Wake Island, one was on the lagoon beach April 20, 1952, one was seen October 22, 1953 and several on March 9, 1963, these around the pond in the intersection of the runways. They were very wary and hard to recognize with certainty, even with binoculars. Two were seen on Eniwetak Islet, Rongerik, on February 11, 1956. One was on a rubble tract along the spit extending from the west end of Utirik Islet, Utirik Atoll, February 13, 1956.

Limosa lapponica   Bar-tailed Godwit (?)

A large bird was seen on February 2, 1956 at the southwest end of Kwajalein Islet, Kwajalein Atoll, in weedy ground. It was brownish, with dark patches in wings. The neck was long and when on alert was held very erect....the head and throat with a large dark patch on each side. It flew off over the sea and circled around to land again on the other side of the airstrip. The rather reddish-brown color, the size, and posture suggest it may have been a Bar-tailed Godwit.

Sterna sumatrana   Black-naped Tern

This is a delicate little tern, found in small numbers on most of the northern Marshall Islands. They were mostly seen on gravel or sandbars and horns on the inner or, more rarely, outer, corners of islets. Their eggs are laid on gravel at the bases of these horns or spits, with no nest at all, the eggs blending in prefectly with the gravel on which they are placed.

They were first seen on Ailuk, where a flock of 10 was sitting on a sandbar with several noddies at the north end of Kappen Islet on December 26, 1951. They were pearl-gray on the back, and had a black band around the head, continuous with the black bill. The black band was more conspicuous than in Mayr's plate. They seemed reluctant to fly. When approached closer than 15 meters they would fly a short distance, then settle down again. Finally, after doing this 8-10 times, they flew away, flying low over the water.

On Ujae Atoll, on February 18, 1952, one was seen flying over the south end of Bock Islet. Seven were observed on Rua, on the inner south sand spit of the islet, on February 22. Two nests were here on bare gravel at the base of the spit, just above high-tide level. There were two eggs in one clutch, one in the other, very well concealed by their resemblance to their surroundings. They seemed identical in size, shape, color, and markings to the eggs of Gygis alba, 38 mm long, gray ground color with scattered brownish markings. Four birds were seen on the inner southwest sand spit of Alle Islet on March 10, 1952; one clutch of eggs was laid on a small collection of pebbles on otherwise bare sand, just above high-tide level. The eggs were very well concealed, only the frantic protests of the birds calling my attention to them, even though I had been walking around them for some minutes. Then I had to look carefully before locating them. These were exactly as described above. As long as I was in the vicinity, even during the time I ate my lunch sitting on a rock 15-20 meters away, the four birds protested noisily, "yak, yak, yak," "yip, yip, eep," "aa," "yak, yak, yip."

On Ujelang Atoll, February 16-25, 1952, three terns were seen on Kiloken Islet, and two on the east end of Ujelang Islet, flying and making a harsh low croaking note. On Wotho, February 12-16 and March 18-22, small flocks were seen on the inner corners of various islets, invariably on or over sand horns or beaches on inner corners of the islets. On Enearik Islet there were 8 on the east corner and 4 on the west corner. On Ombelim there were 10 on the inner beach--the islet is too short for corners to be distinguished. Six were seen fishing over the lagoon near Wotho Islet at 6:30 p.m., and one was with a flock of other terns near Majurwon at about 4 p.m. On February 5, 1950, two were seen flying over the lagoon side of Ebeye Islet, Kwajalein Atoll.

On Bikar Atoll, August 7-11, 1952, small groups of 3 to 10 of these birds were seen flying over or resting on open gravel bars and beach rock, especially between Almeni and Jaliklik Islets.

Sterna lunata Bridled Tern or Gray-backed Tern

One bird seen flying over the north end of Bikar Islet, Bikar Atoll, August 7-11, 1952, was identified as this species. On Pokak, small numbers of Bridled Terns were seen, only on North Islet, where they were flushed with some reluctance from their resting places on the ground in the interior of this barren rocky islet. They circled around, protesting violently, with harsh noises, at the intrusion. They were medium sized, gray above, with a black crown, black feet, and a forked tail.

The species may have been present elsewhere, but we did not see it except on these two dry northern atolls. There is some discrepancy between the treatment of this species and S. anaetheta in Mayr's book and Baker's "The Avifauna of Micronesia," p. 160, 1952. As Mayr's was used for identifications, and as Baker does not describe these species, the bird observed is named in accord with Mayr, though the distribution given for S. anaetheta by Baker suggests that species rather than S. lunata.

Sterna fuscata Sooty Tern

Sooty Terns are usually seen near their rookeries during the breeding season, and seldom at other seasons or places. They are extremely gregarious birds, laying their eggs on the bare ground, very close together; in the Marshalls in open or almost open areas, not necessarily so elsewhere. No nesting material is used, and when the eggs are on gravel or coarse sand they are very hard to see. They are variously colored, from grayish to brownish, variously mottled and speckled with brown or dark brown.

Our first Sooty Terns were seen on Taka Atoll. A few were flying around Taka Islet, on December 7, 1951, but it was on Matwerok Islet, where I spent the night of December 8-9, 1951, that I became really conscious of the enormous numbers of terns that inhabit a single rookery. On the seaward side of the islet the ground was literally black with Sooty Terns. Between the first sparse row of Tournefortia bushes the ground was scattered with their eggs, laid on the absolutely bare gravel and sand. Walking through this area it was hard to avoid stepping on the eggs, because they were so numerous and hard to see. When approached the birds rose in the air by the thousands with a deafening clamor. I camped on the lagoon side of the islet, and at about 6:30 p.m. a great horde of Sooty Terns came circling over my camp, screaming and squawking, and they kept this up continuously until after 7 a.m.

On Ailuk Atoll, on December 28, 1951, a stray Sooty Tern was seen over the lagoon near Bikon and another at the north end of Kapen Islet. There was no evidence of a colony of them on this atoll, however. On Ujelang a considerable number of Sooty Terns and eggs were seen on Jerko Islet, February 4, 1952, but only one or two birds at a time at rare intervals elsewhere in the atoll. The Marshallese gather and eat the eggs. Ted Arnow saw one Sooty Tern on Eniwetak Islet, Kwajalein Atoll on January 23, 1952.

Sooty Terns were seen commonly flying almost anywhere on Bikar Atoll, August 7-11, 1952. On Jaboero Islet, a small gravel bar only very slightly above high tide, vegetated only by Portulaca lutea, is a rookery of thousands of pairs. There were hundreds of eggs not yet hatched, and thousands of newly hatched chicks, which were small, gray-brown, not at all feathered out yet, and very active; quite a few were dead. On rock flats seaward of Almeni and Jaliklik Islets were scattered eggs and shells, and on the northeast extension of Jaliklik was a small rookery with many young birds with wings feathered out. Little or no guano was seen on any of these sites.

The great concentration of Sooty Terns, as of other birds, in the northern Marshalls is on Pokak Atoll. On November 25, 1951, only one pair was seen definitely, flying around the ship near Pokak. On March 25, 1952, numbers of them were seen fishing together with other birds. Four were seen at sea, on July 19, between Wake and Pokak. On our visit from July 20-27, this was probably the most abundant bird on Pokak Atoll. They could be seen at any time flying over the lagoon and neighboring ocean, graceful and sure of themselves. At about sundown numbers of them could be seen in any part of the atoll, flying toward their homes on Kamome Islet. The rookeries were on Kamome, where large areas of ground were occupied by myriads of these birds. The actual parcels of land used as nesting sites and resting places by this gregarious species vary in size from an acre to several acres. They may lie in sparse Tournefortia scrub, but are more commonly in the open part of Kamome Islet, in places sharing ground with shearwaters. Usually in the center of such a rookery the Sida shrubs tended to be suppressed and the bunch-grass (Lepturus) favored. The ground was definitely not noticeably stained with guano, although both adults and young in all stages occupied it in such numbers as to blacken the air when they flew up. A few eggs were seen, lying on the bare ground with no nesting material whatever. The young birds swarmed over the ground in all stages of development from actively running chicks with only their wings feathered to full-grown birds perfectly able to fly, differing from their parents only in plumage. The young had feathers on back and wings tipped with white, and the under parts more or less dark, except for whitish anal region and undersides of wings. If the behavior of the Sooty Terns at Pokak is at all typical, it does not seem likely that Sooty Terns contribute materially to guano accumulations, though a gradual alteration of the lime sand over long periods of time is entirely possible.

On Wake Atoll, April 20-21, 1952, there was a considerable rookery of Sooty Terns on Peale Islet near the LORAN Station. The young were in various stages from pin-feathers to almost full grown. No eggs were seen. In the pin-feather stage the young were sooty brown on the back and sides, light gray downy beneath. Many were seen flying on July 18, 1952. C. G. Johnson reported that the colony at the LORAN Station on Peale Islet had eggs on that date. A small flock was seen near the west tip of Peale Islet on October 22-23, 1953. This was said by LORAN Station personnel to be the new nesting site, selected after they were driven off the old nesting place near the LORAN Station. Nesting was said to have been finished in July, but around this spot still lingered a number of almost fully grown but more or less crippled young ones, as well as some dead birds.

In September 1961 M.-H. Sachet found that the Wake Island colony had moved to Wilkes Islet, just back of Kuku Point. There had been considerable clearing of vegetation in this area, said by local people to have been done to provide nesting space for the birds. However, certain installations had been put in part of the cleared area. A few Sooty Terns were observed on the boulders on the reef at Kuku Point on September 9, but no great concentrations were seen. On September 15 the same place was visited after dark, and the colony had evidently returned, as cries from many birds were heard.

On March 8-9, 1963, this colony was again visited. Thousands of birds were present, with fully grown young, still in dark plumage, but able to fly up when approached. One was caught. It spit up a piece of fish (Sachet). A few adults were also seen on Peale Islet.

Thalasseus bergii   Crested Tern

This is the largest of the Marshall Island terns, and it is easily spotted by its heavy yellow beak. Its crest is not very obvious, but may at times be seen. It is not one of the more abundant sea birds in the Marshalls. There are usually a few pairs on an atoll, and they may be seen flying and hovering over lagoon reef flats, looking for small fish.

On February 29, 1952, 6 Crested Terns were fishing in the lagoon near the pier (and sewer mouth) on Kwajalein Islet, Kwajalein Atoll. Three or four could be seen almost any time during January 8, circling over the lagoon beach near Lae Islet, Lae Atoll, diving and fishing. At Ujae Atoll on March 8, 2 were seen over the lagoon, Ebeju Islet; on March 9, 5 were seen on Bikenbar Islet and one over the lagoon in the north part of the atoll; on March 10, 8 were seen over the seaward reef flat, Alle Islet; and on March 15, one was flying over the lagoon near the windward reef about 2 miles north of Ujae Islet. They are here called "he'er" (name tied to this species only by description by native, as no bird was seen at the time). On Wotho Atoll, February 16-23, 1952, the Crested Tern was rare, possibly only one or two pairs. One was seen at sea west of the atoll and 2 on Ombelim Islet. On Ujelang, February 3-8, one was seen over the middle of the lagoon; four commonly patrolled the lagoon beach near the east end of Ujelang Islet; and one was on the lagoon side of Kiloken Islet. On Utirik one was seen flying over the seaward side of Utirik Islet, February 13, 1956.

On Bikar, August 7-11, 1952, pairs or single birds were seen occasionally flying over reef flats, making harsh grating noises. They were commoner on Pokak than elsewhere, July 20-27. At any time of the day from one to 6 of these ungainly birds could be seen patrolling the shallow water, diving recklessly for small fish. Their disagreeable screaming or squawking was one of the most frequent sounds.

Procelsterna cerulea   Blue-gray Noddy

This is not a common bird in the northern Marshalls. We found it in small numbers only, just on Bikar and Pokak, of the 16 atolls visited.

A beautiful little bird, Procelsterna seems rather closely associated with open, unvegetated gravel ridges, against which its blue-gray color affords astonishingly good protection.

It is commonest on Pokak Atoll, where the following extract from my notebook was written, dated July 20-27, 1952:

'This delicate little bird, not seen elsewhere during this survey, is smaller than the fairy tern, and of exactly the blue-gray shade of the boulder and cobble ridges and flats so characteristic of Pokak landscapes. Small numbers of these birds are to be seen almost anywhere. Their curiosity is as well developed as is that of the fairy tern, and they seem even less afraid. On the more wooded islets, as Sibylla, Breje, Pokak, they seem to prefer the seaward side, though by no means staying there only. Possibly the greater prevalence of blue-gray stony ridges and flats on the outer sides is the reason for this. On North Islet, and Kamone, they are much more abundant and more persistently curious than elsewhere, and one can go nowhere on these islets without a constant accompaniment of their "Whirrrrr, Whirrrrr." When caught and held in the hand, one of these birds disgorged an astonishing quantity of partially digested dark blue fish.

'Although their behavior suggested that they might be nesting, no eggs or young were seen. One bird was flushed from a small empty nest, merely a slight accumulation of grass stems and feathers in a slight depression sheltered by 2 rocks on the boulder ridge on the seaward beach of Breje. This was probably one of their nests, and their color would suggest this as their normal habitat. It may be noted that, on Pokak, the web between their toes is a dull orange, rather than canary yellow.'

On Bikar Atoll, in August 1952, 3 solitary individuals were seen, flitting over gravel bars and flats on Jaliklik Islet. A single bird was sitting on a nest with an egg, on the lagoonward end of a gravel bar between Almani and Jaliklik Islets. It left the nest with no great reluctance when approached within 1 or 2 meters, but did not go far. The egg was whitish with a few dark speckles. The nest was only a few grass culms in a very slight depression in the gravel, very effectively camouflaged, especially when the bird was sitting on it.

Anous stolidus Common Noddy

The Common Noddy is one of the common widespread sea birds in the northern Marshall Islands. Curiously, it was not seen on Utirik Atoll. The Marshallese call it "pijuak" (Ujae, Ujelang) or "bijuak" (Ujelang), and use it as food when they can catch it. It nests on the ground, in bushes, and in the crotches of trees. Its nest is an untidy collection of small twigs, often 30 cm across or more but never more than 5-10 cm high. Usually a number of nests are found in the same area, but it is not a conspicuously gregarious nester. Several birds may be seen flying together, but large flocks are seen only when fishing, possibly just accidental aggregations attracted by schools of fish, and when resting on sand spits or bars. They were frequently seen fishing during the day in the lagoon or in the ocean near an atoll.

Many were seen on Watwerok Islet, Taka Atoll, December 8-9, 1951, nesting on open pebble flats on the east end of the islet and in trees generally. On December 16, 1951 several were seen on the seaward side of Likiep Islet, Likiep Atoll. They were quite common on Jemo Island, December 18-22, but not seen nesting. On Ailuk a few were seen on Konwon, Tabu, Enenkonge, Eneljar, and Enijabrok Islets, December 26-27, 1951, and perhaps some of those seen fishing and sitting on sand spits and bars were this species.

On Kwajalein Atoll, January 15, 1952, Common Noddies were quite plentiful generally on Lojjaiong and Lojjairok Islets. One or two were obviously gathering nesting material. Many were seen at Enebuoj Islet, on January 19, especially on and over the outer reef flat. A few were seen on Eniwetak Islet on January 23. On August 3, 1952, one Common Noddy was the only sea bird seen near Enelapkan Islet.

Common Noddies were plentiful on Lae Atoll, January 5-10, 1952, and were seen over practically all islets and all parts of the lagoon visited, in numbers up to a dozen at a time. On Enejelto Islet, quite a few were nesting high in Ochrosia trees, and on Bikalabet Islet a flock of 20-30 were sitting on a sandbar. This bird was seen at least occasionally on all islets visited on Ujae Atoll, February 16-23 and March 2-11, 1952. Some were seen gathering nesting material in the forest on Bock Islet. Hundreds were seen on Bokerok Islet, and quite a few on Rua Islet, February 22, where three nests were found in a Terminalia samoensis tree on the seaward side. On Wojia Islet 6 were seen pursuing a Fairy Tern with a fish in its beak. The tern escaped. On March 9, 1952, at low tide an enormous flock of hundreds or even thousands of noddies blackened a long sand spit uncovered at low tide. They seemed to be holding the usual "conference" so characteristic of Common Noddies. In the afternoon at high tide many were flying over the islet. One nest with an egg in it was found in a bush about 2 meters above the ground. The egg was white with brown markings. The old bird protested and flew around close by, trying to drive me off. Many were seen flying about Enelamoj Islet, and they were abundant on Alle Islet. Here one was nesting in a big crotch of a Pisonia tree about 5 meters above the ground. The nest in this broad depressed crotch consisted of very little material, a few twigs and leaves, not at all typical for this species. On Ujae Islet where the people live, only 6 noddies were seen, March 13, 1952.

On Ujelang Atoll, February 3-8, Common Noddies were also abundant. The Marshallese gather and eat the eggs in large numbers, and also eat the fully feathered young birds. The birds' habit of sitting in large numbers on beaches and reef flats was very noticeable on all islets where they were common. Hundreds were seen on Bikom Islet, the last islet on the windward reef to the west, where they were nesting in Pemphis acidula trees. Fewer were seen on Ujelang Islet, where the village is located, than on the others. On Nelle Islet hundreds were seen sitting in crowds on the beaches and flying overhead. Large numbers of wings were lying on the ground around a temporary native camp. There were quite a few nests here on the ground, with young of various ages. Hundreds were also seen on Bieto Islet, some nesting, mainly in trees. These were white when very young, soon turning dark gray. When pin-feathers have appeared on the wings and tail the white forehead has developed. On Bokan Islet they were nesting on the ground. They were very abundant on Jerko Islet, nesting on the ground in the same area as the Sooty Terns. Most of the nests there have eggs. On Ujelang they used rather little nesting material.

On Wotho Atoll, there were usually some to be seen flying overhead, February 12-16, 1952. There were a considerable number along the seaward beaches, small or moderate numbers over the lagoon and sea, and a few on the larger islets. Many were on Enejelto Islet, and many birds and several nests on Enearik Islet, the nests with downy young. One bird scared up there flew with difficulty, as it had Pisonia grandis fruits stuck over its feathers. There were several nests on Biken Islet, and many birds were seen on Bokanaetok Islet. Some birds and a nest were on Eneobnak Islet, the nest in a Guettarda speciosa tree. Noddies were commonly seen in the middle of the day in groups on the beaches. On February 15, 1952, F. Stearns MacNeil saw one pick up a neritid snail from the reef, fly high in the air with it, drop it, and follow it down and eat it after the hard shell was broken. Fragments of these shells are common on the reef rocks.

Three Common Noddies were seen, February 7, 1956, on Rongelap Islet, Rongelap Atoll, flying out to sea; toward evening 2 were seen over the lagoon. A few were also seen on Kabelle Islet and here 5 nests were seen. These were empty, but eggs were found by other members of the party. These nests were loosely constructed of dried fruiting inflorescence of Tournefortia argentea. Two Common Noddies were seen on Eniwetak Islet, Rongerik Atoll, February 11, 1956. On February 10, a few were seen on Sifo Islet, Ailinginae Atoll.

On Bikar Atoll, March 24, 1952, some noddies were seen flying, probably this species. On August 7-11, four birds were seen on Jaliklik Islet, as well as 2 nests in crotches of Pisonia trees.

Common Noddies were common but by no means abundant generally on all the islets of Pokak Atoll, July 20-27, 1952. Their nests were observed most commonly on Kamome Islet, where they were scattered in shrubs, on grass tufts, on rocks, and on the ground, with eggs at this season. The adult birds here were of a lighter brown color than those seen elsewhere in the Marshalls. When sitting on their nests they would permit a person to approach to within 15 meters before flying up. Then they circled about screaming at anyone examining their nests. These were, as usual, untidy accumulations of twigs. The birds, here as elsewhere, tend to sit in groups on sandbars and rubble flats exposed in the lagoon, apparently doing nothing but enjoying the sun and each other's company.

On Wake Atoll, April 20-21, 1952, a few Common Noddies were seen flying and one nest was found. Birds were not seen in it so it may have been unoccupied. One bird was seen on July 18, 1952, flying. On Peale Islet, October 22-23, 1953, many were seen roosting or flying with frigatebirds around the old frame of a bombed-out building. There was one nest with a half-grown young bird. On Wilkes Islet, September 9-12, 1961, Common Noddies were seen in small numbers sitting on boulders just off Kuku Point (Sachet). In 1963, March 7-9, they were seen in exactly the same place; a few were also on the old Pan American pier on Peale Islet.

Anous tenuirostris White-capped Noddy

The White-capped Noddy is almost as common in the northern Marshall Islands as the Common Noddy, in places more so. It is a slightly smaller bird with a more irregular, uncertain flight, darker in color, with a more pronounced white forehead. It is much more gregarious, especially when nesting and fishing. Its nests, made of Tournefortia argentea leaves, compact and plastered together with excrement, much smaller than those of the Common Noddy, are found in groups of dozens, or even hundreds, crowded together in very small areas. Sometimes dozens of these nests will be in a single Pisonia tree. The guano under these rookeries contributes perhaps more than that of any other bird to the formation of atoll phosphate rock (Fosberg, Soil Science 78: 99-107, 1954, and American Journal Science 255: 584-592, 1957).

On Watwerok Islet, Taka Atoll, December 7-8, 1951, White-capped Noddies were common, nesting in trees. Their eggs were light colored, only lightly speckled. Several were seen on Jemo Island, December 18-22. On Ailuk Atoll, December 24-31, they were more common than the Common Noddy. Large flocks, of as many as a hundred, were seen fishing in the lagoon, and occasional individuals were seen on most islets visited. On Kwajalein Atoll 4 were seen flying over the lagoon just off Lojjaiong Islet, on January 15, 1952. On January 23, hundreds were seen nesting high in the Pisonia grandis trees on Eniwetak Islet. From January 27 to February 1, 1952, a flock of 2-3 dozen were watched fishing in the lagoon off Kwajalein Islet. They were frequently seen around the anchored ship, where schools of tiny fish were to be seen almost any time. The birds would rest on the water, then fly around. When bonito would chase the small fish to the surface the noddies would fish frantically. When full they would rest again on the surface.

On Lae Atoll, January 6-10, 1952, this species was very scarce. Only one was seen, on the north side of the lagoon, January 8. On Ujae Atoll, February 16-21, 1952, White-capped Noddies were nesting abundantly and gregariously in Pisonia trees on Bock and Bokerok Islets and were to be seen in hundreds flying around these islets. The young were fully feathered out but not yet flying. The Marshallese collect these young in some numbers for food. They built a fire at the base of a huge Pisonia tree on Bock Islet, loaded with nests. It burned all day, and finally one half of the tree fell, at least 5 or 6 dozen young birds were collected. Here the birds are called "jagarik" but the young at this stage are called "nemajelij kon." They were also common on Alle Islet, a dozen nests in a close group in Pisonia and Terminalia trees.

On Ujelang Atoll, February 3-8, 1952, the White-capped Noddies were seen more locally than Common Noddies, but in considerable numbers. Many were seen on Bieto Islet, some nesting. Hundreds were nesting on Kirinyan Islet, concentrated in certain patches where there were many nests to a tree; the largest such patch noticed, about 20 by 40 meters, had several hundred nests. These nests contained more material than those of Common Noddies, chiefly Tournefortia leaves, were much more compactly constructed, but of smaller dimensions. Eggs and young birds, up to completely feathered-out ones, were in the same colonies. They were also seen nesting on Bikom Islet, and on Bokan, where their numbers were smaller than on Kirinyan. Here they also nested gregariously, in trees. The fledgling White-capped Noddy seems to develop its white forehead sooner and more conspicuously than the Common Noddy; it shows even before pin-feathers appear. The natives of Ujelang collect both eggs and young birds for food.

Noddies were commonly seen fishing in the lagoon and the open sea around Wotho Atoll at any time of the day February 12-16, and March 12-22, 1952. Many nests were seen in trees on Wotho Islet, on March 20. In February some nests were seen in Ochrosia oppositifolia trees on Enejelto Islet, and about 20 nests on Enearik. Many nests were seen on Biken Islet, in Pisonia and Tournefortia trees, and a small group of nests were in Pisonia on the seaward side of Kabben Islet. Hundreds of nests and a multitude of birds were seen in Pisonia and Tournefortia trees on the seaward side of Ombelim Islet.

This species was not plentiful on Bikar Atoll, August 7-11, 1952. A single bird and three nests were seen on Almeni Islet in the Pisonia forest, and a small colony of a couple of dozen nests and a few birds in Pisonia trees on Jaliklik Islet. Very few birds were seen outside the forest, and none at all were seen on Bikar Islet. On February 9, 1956, a few birds and several nests were seen on Kabelle Islet, Rongelap Atoll. On February 10, 1956, several were seen on Sifo Islet, Ailinginae Atoll. This species was less plentiful than the Common Noddy on Pokak Atoll, July 20-27, 1952. It was seen occasionally fishing in the lagoon or just outside. Small groups of nests were placed in the Pisonia trees in the groves on Kamome Islet, but it was not noted whether there were eggs.

Gygis alba Fairy Tern, White Tern, or Lovebird

This most charming and beautiful of sea birds was the only species seen on all of the atolls visited. It is also the least afraid of man of any observed, even on inhabited atolls. On the less frequented islets its curiosity is amusing to watch, as the birds, several to swarms, will hover over the heads of visitors and follow them a few feet overhead. If one is quiet he can at times induce one to settle on his head or outstretched hand. The Fairy Tern is definitely a tree-frequenting bird. It lays its eggs in trees if any are available, roosts in trees ordinarily, and when not out fishing is usually seen not far from patches of forest or scrub. Pisonia grandis seems to be the preferred tree, but it is also very frequently associated with Tournefortia argentea. Its normal food seems to be small fish. During the Arno Atoll Survey, in 1950, Joe Marshall found in the crop of a specimen that he shot a seed later identified by me as the beach morning-glory, Ipomoea pes-caprae, a plant not known from Arno Atoll, though common on Majuro, a few miles away. It may have been a drift seed, picked up on the beach, and was probably picked up for a gizzard stone, rather than for food.

My first sight of Fairy Terns in numbers on the 1951-52 trip was on Eeluk Islet, Utirik Atoll, where a great cloud of them were in the air when I was in the brushy part of the islet. The egg of one of them lay on a dead stub of a branch of a Tournefortia tree, balanced in a slight depression. Its ground color was a pale brownish gray, irregularly mottled with brown-gray, brown, and very dark brown. On Taka Atoll, December 7-8, 1951, on Lojiron and Watwerok Islets, they were very abundant, nesting in bushes and trees. The eggs were laid on bare branches wherever there was a knothole or any slight irregularity. The eggs and young in various stages were scattered generally over the wooded parts of the islets. They were occasional on Jemo Island, December 18-19, 1951, but not seen nesting. On December 24-31, 1951, on Ailuk Atoll, a few were seen flying over the southern part of the lagoon, and small numbers were on or near almost all islets visited, more over the tiny uninhabited northern islets. On the islet just north of Baojen Islet, one was seen with an egg, and a flock of 15 were seen fishing. An occasional one was seen on Likiep Islet, Likiep Atoll, on December 16, 1951.

Fairy Terns were seen, but not more than half dozen at a time, on or over practically all islets visited on Lae Atoll, January 6-10, 1952. On Kwajalein Atoll, on January 15, a number were seen flying over Lojjaiong Islet, several over Enebuoj Islet on January 19, and large numbers, including several young ones, on the still densely wooded Eniwetak Islet.

On Ujae, in February 1952, large numbers of Fairy Terns were seen. The Marshallese name here is "mojau." There were many in the trees and flying overhead on Bock Islet. One was seen in the pinfeather stage on February 18. Here, along passages and beaches, they could be seen occasionally at any hour of the day carrying small fish in their beaks. Hundreds were seen flying overhead on nearby Bokerok Islet, hundreds also on Rua Islet. They were only occasionally seen on Ebeju Islet, but here on February 25, 1952, 3 eggs were spotted on Tournefortia branches, 3 on Pisonia, one broken, one on the ground under a Pisonia tree, and 2 young birds almost feathered out. The eggs measured were 38 mm long. They were rare on the inhabited Ujae Islet. Hundreds were seen over Bik Islet, and many on Enylamij Islet. They were abundant on Alle Islet, where one with an egg on a Pisonia branch about 8 m above the ground drove off a noddy much larger than itself, when it approached. One over the lagoon with a fish in its mouth outflew and eluded 6 noddies that were pursuing it. Notes taken on the spot read "On Wojia Islet over the lagoon beach, six noddies were vigorously pursuing a fairy tern that had a small fish in its beak. The chase lasted several minutes, but in spite of the wavering, fluttering type of flight of the tern, it got away from its apparently surer-flying assailant."

On Ujelang Atoll, February 5-8, 1952, a few Fairy Terns, here called "juuwi" or "chew'wi," were seen on all islets. Many were seen on Nelle Islet, also on Jerko. No eggs were seen, though the birds behaved as though they might be nesting.

On February 15, 1952, Fairy Terns were seen frequently over the thin scrubby forest on Wotho Islet, Wotho Atoll, but not more than a few at a time. On this atoll, in February, they could be seen generally almost anywhere, flying over the lagoon or open sea in pairs or small groups, or fishing in flocks with other terns, or flying overhead on islets, protesting intrusion into their privacy. Probably in most such cases there are eggs on the bare branches of the trees, but they are seen only with difficulty. Many birds were seen on Ombelim Islet, where one egg was seen on a Tournefortia branch, also one half-feathered young and one fully feathered young. On Enejelto Islet many were flying overhead, protesting as though they had eggs in the trees. Many were flying over the long sand spit called Bokenaetok, also on Eneobnak Islet.

On Ailinginae Atoll, February 10, 1956, hundreds were seen on Sifo Islet. On February 11, 1956, quite a few were observed on Eniwetak Islet, Rongerik Atoll. Many were seen on Rongelap Atoll, on Kabelle Islet, February 9, and on Gegen Islet, February 15, 1956. From the ship, on November 26, 1951, Fairy Terns were seen very commonly flying over all three islets of Bikar Atoll. On March 24, 1952, also from the ship, they were seen flying over the north, east, and south sides of the atoll. August 7-11, 1952, were spent on land on Bikar Atoll. Fairy Terns were common generally, hundreds of them on Almeni Islet, flying everywhere, especially over Pisonia trees. A few downy young were in the trees.

Pokak Atoll is the home of great numbers of Fairy Terns, just as of other species of sea birds. They flew around our ship during our abortive visits on November 25, 1951, and March 25, 1952. During July 20-27, 1952, they were to be seen at any time on any of the islets, over the lagoon, and over the nearby ocean. During the hottest part of the day they tended to rest on the branches of trees, or, less often, on the ground or on rocks. They hovered in swarms over anyone walking through the woods or bush, venturing almost within arm's reach. Their eggs were found, occasionally, almost anywhere in Tournefortia trees, and very abundantly in Pisonia in the groves on Kamome Islet, balanced, in the usual fantastic manner on any horizontal limb, on a fork of a tiny branch, or in a slight depression anywhere. One was seen on a large boulder on South Islet, where there were no trees. The eggs on Pokak Atoll have about the same range of color variation as seen elsewhere in the Marshalls, but here the small end is much less pointed than seen elsewhere. In fact, it is almost the same shape as the larger end. The birds are induced to leave their eggs only with some hesitation. The way they daintily back away from the eggs when leaving is pleasant to watch, also their careful way of approaching and settling down on the egg when they return. The Fairy Terns here seem to have a more pronounced blue basal half of the beak than those seen elsewhere.

Several were seen flying on *Wake Atoll*, Wake Islet, April 20-21, 1952, and others around *Pisonia* trees on Peale Islet, October 22-25, 1955. A few were seen in and over the *Tournefortia* forest both on Peale and Wilkes Islets, on September 5, 1961 (Sachet) and March 7-9, 1963.

Eudynamis taitensis New Zealand Cuckoo

The only indigenous passerine species in the Marshalls was only seen once, flying over the seaward beach and into the trees on Likiep Islet, *Likiep Atoll*, on December 14, 1951. This may be the second most northerly record for this bird. It was collected on Bikini by J. L. Morrison in 1946 and 1947. It seems commoner farther south, as two were seen on *Jaluit Atoll* in 1958.

Acridotheres tristis Indian Mynah

Several pairs were established and very much at home on Kwajalein Islet, *Kwajalein Atoll*, in 1952, but none were seen on February 2, 1956, or in 1958 or 1960.

Padda oryzivora Java Sparrow or Java Finch

A cage of the attractive small finches with large conical red bills, commonly called Java Sparrows, was seen on Wake Island in a house on April 19, 1952.

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ATOLL RESEARCH BULLETIN

No. 115

Marine benthic algae from the leeward Hawaiian group

by

Roy T. Tsuda

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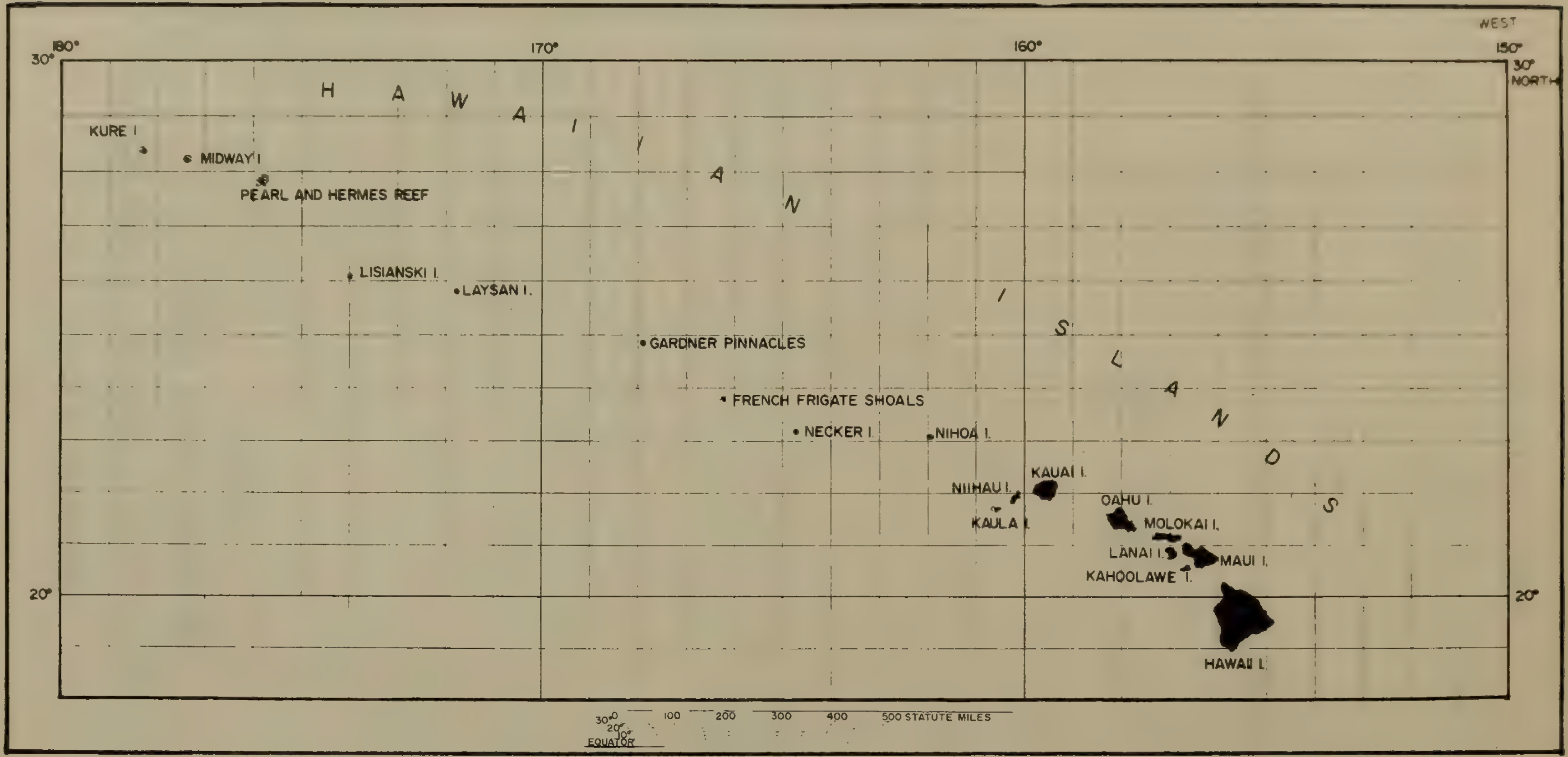
WEST
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H A W A I I A N I S L A N D S
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MIDWAY I
PEARL AND HERMES REEF
LISIANSKI I.
LAYSAN I.
GARDNER PINNACLES
FRENCH FRIGATE SHOALS
NECKER I.
NIHOA I.
NIIHAU I.
KAULA I.
KAUAI I.
OAHU I.
MOLOKAI I.
LANAI I.
MAUI I.
KAHOOLAWE I.
HAWAII I.
0 100 200 300 400 500 STATUTE MILES
30° 20° 10°
EQUATOR

Fig. 1. Map of the Hawaiian Islands showing the relative position of each of the islands reported on.

Marine Benthic Algae from the

Leeward Hawaiian Group[1]

by Roy T. Tsuda[2]

The following is an account of all the marine benthic algae accumulated by the author from various collectors from six of the nine islands in the Leeward Hawaiian Group (Nihoa, Necker, French Frigate Shoals, Lisianski, Pearl and Hermes Reef, Kure). The islands comprising this group (Fig. 1) consist of remnants of nine former high islands which at present make up low volcanic islands, reefs, and atolls. They extend approximately 1300 miles northwest from Kauai and are located between 23° 05' N. and 28° 25' N. latitude and 161° 58' W. and 178° 25' W. longitude. For further information on the geography and history of each of these islands, see Bryan (1942).

Past published papers on the marine algae concern only three of the nine islands. These are Schauinsland (1899), Reinbold (1899), Lemmermann (1905), Tsuda (1965) on Laysan Island; Buggeln (1965) on Midway Island; and Howe (1934) on Pearl and Hermes Reef.

The fifteen species of algae reported in Howe (1934) on Pearl and Hermes Reef and one species of *Turbinaria* reported in Taylor (1964) from French Frigate Shoals are incorporated in this present paper. Except for them, all species listed represent new records. The recent algal collections made from Laysan Island by Mr. C. R. Long in September 1964, are excluded since no new records were found. Any name which is now relegated to synonymy is cited with the currently accepted name.

Also included in this paper are the corrected specific epithets of three species of *Liagora* and one species of *Halimeda* which were reported inaccurately from Laysan Island (Tsuda, 1965) and Midway Island (Buggeln, 1965).

Below is a list of the islands with the collectors, dates and specimen numbers as available. The initials within the parentheses identify the specimen numbers of Dr. Maxwell S. Doty, Dr. Charles H. Lamoureux, Mr. Ronald Walker, and the author.

NIHOA ISLAND (23° 05' N. Lat., 161° 58' W. Long.):
E. Christophersen, July 1924; R. Walker, March 1964 (RW 2).

NECKER ISLAND (23° 10' N. Lat., 164° 41' W. Long.):
E. Christophersen, July 1924; C. R. Long, September 1964 (RT 938-955).

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[1] Technical Report No. 7, Hawaii Marine Laboratory, University of Hawaii.

[2] Department of Botany, University of Hawaii, Honolulu, Hawaii 96822.

FRENCH FRIGATE SHOALS (23° 50' N. Lat., 166° 15' W. Long.): C. T. Crocker, December 1936 (in Taylor, 1964); R. Rogers, March 1961 (MSD 19476); C. R. Long, September 1964 (RT 931-937).

LISIANSKI ISLAND (26° 02' N. Lat., 173° 59' W. Long.): S. C. Ball (Tanager Expedition), April 1923; A. L. Young, August 1964 (RT 637-645); C. R. Long, September 1964 (RT 920-928).

PEARL AND HERMES REEF (27° 50' N. Lat., 175° 50' W. Long.): P. C. Galtsoff, Summer 1930 (in Howe, 1934); E. C. Jones, June 1956 (MSD 13346); A. L. Young, August 1964 (RT 613-633); C. R. Long, September 1964 (RT 899-919).

KURE ATOLL (28° 25' N. Lat., 178° 25' W. Long.): C. H. Lamoureux, September 1961 (MSD 19573-19576, CHL 2778); A. Anderson, March 1965 (RT 980-986).

In the following annotated list, the specimen numbers are listed with the species and by their use the collectors can be determined.

MYXOPHYTA

Species determinations in this group are contributed by Dr. Francis Drouet.

Lyngbya aestuarii (Mert.) Lyngb.

French Frigate Shoals: RT 937 (East Island - on reef flat).

Lyngbya majuscula (Dillw.) Harv.

Pearl and Hermes Reef: RT 914 (North Island - on reef flat), RT 916 (in central lagoon); Kure Atoll: MSD 19576A (Green Island - on reef flat).

Oscillatoria chalybea Mert.

Necker Island: RT 938 (west point of island).

Schizothrix mascarenica Gom.

Kure Atoll: CHL 2778 (Green Island - forming crust in sand about 5 mm thick on edge of dune facing lagoon beach).

CHLOROPHYTA

Bryopsis pennata Lamx., 1809a: 134, figs. 1a-b, pl. 3; Egerod, 1952: 370, fig. 7.

Necker Island: RT 950; *Lisianski Island*: RT 736 (on reef flat).

Caulerpa racemosa var. clavifera (Turner) Weber-van Bosse, 1898: 361, pl. 33 (figs. 1-5).

Necker Island: Christophersen (det. by Dr. W. J. Gilbert).

Caulerpa racemosa var. *imbricata* (Kjellm.) Eubank, 1946: 423, fig. 2w.

Necker Island: RT 944.

Caulerpa racemosa var. *laetevirens* (Mont.) Weber-van Bosse, 1898: 366, pl. 33 (figs. 8, 16-22).

Necker Island: Christophersen (det. by Dr. W. J. Gilbert).

Caulerpa racemosa var. *peltata* (Lamx.) Eubank, 1946: 421, figs. 2r-s.

Necker Island: RT 943.

Caulerpa serrulata (Forssk.) J. Ag. *emend.* Boergesen, 1932: 5, pl. 1 (fig. 2).

Pearl and Hermes Reef: Howe (in a meter of water).

Caulerpa taxifolia (Vahl) C. Ag., 1822: 435; Eubank, 1946: 417, figs. 2f-g.

Nihoa Island: Christophersen (det. by Dr. W. J. Gilbert).

Chaetomorpha antennina (Bory) Kützing, 1849: 379; Boergesen, 1940: 38.

Necker Island: RT 953.

Chlorodesmis hildebrandtii A. & E. S. Gepp, 1911: 16, 137, figs. 74-75; Egerod, 1952: 377, fig. 9b, pl. 34a.

Lisianski Island: RT 644 (small filaments about 2-3 mm in length attached to coral).

Cladophora sp.

Pearl and Hermes Reef: RT 627 (Bird Island - entangled mass of yellowish-green filaments with spongy texture).

Codium arabicum Kützing, 1856: 35, pl. 100 (fig. II).

(*Codium coronatum* Setchell)

Pearl and Hermes Reef: Howe (in 3 meters of water). Egerod (1952) relegates *C. coronatum* to synonymy under *C. arabicum*.

Codium edule Silva *in* Egerod, 1952: 392, figs. 18a-c, pl. 35.

French Frigate Shoals: RT 932 (Trig Island); *Lisianski Island*: RT 927 (on eastern beach).

Dictyosphaeria cavernosa (Forsskål) Boerg., 1932: 2, pl. 1 (fig. 1); Egerod, 1952: 350, fig. 1e-g.

Kure Atoll: RT 982 (Green Island - beachdrift).

Distyosphaeria versluysii Weber-van Bosse, 1905: 144; Egerod, 1952: 351, figs. 1a and 2h-k.

Lisianski Island: RT 642; *Pearl and Hermes Reef*: RT 903 (Southeast Island - beachdrift).

Enteromorpha tubulosa Kützing, 1856: 11; Dawson, 1954: 384, figs.6a-b.

Pearl and Hermes Reef: RT 911 (Southeast Island - on rocks on west side of island).

Enteromorpha sp. 1

Lisianski Island: RT 645 (on coral); *Pearl and Hermes Reef*: RT 628 (North Island - on coral).

Enteromorpha sp. 2

Kure Atoll: MSD 19576D (Green Island - small thallus branching profusely from base).

Enteromorpha sp. 3

Pearl and Hermes Reef: RT 913 (Southeast Island - in shallow pool).

Halimeda discoidea Decaisne, 1842: 91; Hillis, 1959: 352, pl. 2 (fig. 5), pl. 5 (fig. 11), pl. 6 (fig. 11), pl. 7 (figs. 9-10), pl. 8 (figs. 5-8), pl. 11.

Lisianski Island: RT 638, RT 922 (on eastern beach); *Pearl and Hermes Reef*: Howe, as *H. cuneata* Hering (in a meter of water). Hillis in her monograph of the genus *Halimeda* lists the specimen identified by Howe as *H. cuneata* Hering under *H. discoidea* Decaisne.

Halimeda opuntia (L.) Lamx., 1816: 308; Hillis, 1959: 359, pl. 2 (figs. 7-8), pl. 5 (figs. 3-4), pl. 6 (fig. 6), pl. 7 (fig. 3), pl. 10.

Pearl and Hermes Reef: Howe (small segmented form in about 7 meters of water); *Midway Island*: MSD 18707, MSD 18738, MSD 18747, MSD 18758 (as *H. incrassata* (Ellis) Lamx. in Buggeln, 1965); *Laysan Island*: Tanager Expedition (as *H. lacunalis* Taylor in Tsuda, 1965).

The author in an earlier (1965) paper had listed *H. lacunalis* Taylor as occurring on Laysan while Mr. Richard Buggeln listed *H. incrassata* (Ellis) Lamx. as occurring on Midway (Buggeln, 1965). After a more thorough study of these two specimens, Mr. Buggeln and the author agree that both are juvenile forms of *H. opuntia*, with this decision later verified by Dr. William J. Gilbert.

These two specimens each have a single distinct holdfast, while anatomically the central filaments at the internode are fused in pairs and the utricles fall within the size range as specified in Hillis(1959).

Microdictyon setchellianum Howe, 1934: 38; Egerod, 1952: 366, figs. 6c-g, pl. 33.

Necker Island: RT 954; *French Frigate Shoals*: RT 933 (Trig Island); *Pearl and Hermes Reef*: Howe (in about 7 meters of water), RT 618 (Bird Island - epiphytic on *Laurencia obtusa* (Huds.) Lamx.), RT 624 (Bird Island), RT 902 (Southeast Island - beachdrift); *Kure Atoll*: RT 986 (Green Island - beachdrift).

Ulva fasciata Delile, 1813: 153; Boergesen, 1940: 10.

Necker Island: RT 942.

PHAEOPHYTA

Colpomenia sinuosa (Roth) Derbes & Solier, 1856: 11; Dawson, 1954: 402, figs. 18a, c, d.

Pearl and Hermes Reef: Howe (epiphytic on *Halimeda opuntia* (L.) Lamx. in about 7 meters of water).

Chnoospora minima (Hering) Papenfuss, 1956: 69.

Necker Island: RT 947.

Dictyota friabilis Setchell, 1926: 91, pl. 13 (figs. 4-7) and pl. 20 (fig. 1).

Necker Island: RT 948 (fragments); *Pearl and Hermes Reef*: RT 617 (Bird Island - epiphytic on *Laurencia obtusa* (Huds.) Lamx.)

Dictyota sp.

Kure Atoll: RT 981 (Green Island - beachdrift).

Hydroclathrus clathratus (C. Ag.) Howe, 1920: 590.

Pearl and Hermes Reef: Howe (in about a meter of water).

Pocockiella variegata (Lamx.) Papenfuss, 1943: 467, figs. 1-14.

Lisianski Island: RT 640 (small prostrate thallus adhering to coral); *Kure Atoll*: RT 985 (Green Island - beachdrift).

Sargassum echinocarpum J. Ag., 1848: 327.

Nihoa Island: EW 2: *Necker Island*: RT 941.

Sargassum obtusifolium J. Ag., 1848: 339.

(*Sargassum vulgare* var. *linearifolium* J. Ag.)

Pearl and Hermes Reef: Howe (in about 7 meters of water on coral and sand, probably unattached).

Howe (1934) places a question mark after this variety, but says that this specimen agrees very well with Yendo (1907). At present, Doty & Newhouse (unpublished manuscript) places this variety under the species *S. obtusifolium* J. Ag. which is circumscribed to include all round and smooth stemmed Sargassums from Hawaii.

Sargassum piluliferum (Turn.) C. Ag., 1821: 27.

Pearl and Hermes Reef: Howe (floating in 2 meters of water), MSD 13346 (floating in 3-4 meters of water), RT 915 (in central lagoon).

Specimen RT 915 is very light brown in color, with proliferations on the main axis, narrow leaf-segments, and numerous air vesicles on short pedicels.

Sphacelaria tribuloides Meneghini, 1840: 2; Boergesen, 1941: 41, figs. 18a-c.

Pearl and Hermes Reef: RT 633A (Bird Island - on coral).

Turbinaria ornata (Turner) J. Ag., 1848: 266; Taylor, 1964: 483.

French Frigate Shoals: (reported in Taylor, 1964); *Lisianski Island*: RT 921 (on eastern side of island); *Pearl and Hermes Reef*: Howe (in about a meter of water), RT 620 (Bird Island), RT 899 (Southeast Island - beachdrift); *Kure Atoll*: MSD 19573 (Green Island - beachdrift).

Zonaria sp.

Pearl and Hermes Reef: RT 613 (Bird Island); *Kure Atoll*: MSD 19575 and RT 980 (Green Island - beachdrift).

RHODOPHYTA

Acrochaetium sp.

Pearl and Hermes Reef: RT 622 (Bird Island - epiphytic on *Turbinaria ornata* (Turner) J. Ag.).

Amphiroa fragillisima (L.) Lamx., 1816: 298; Taylor, 1960: 403,pl. 47 (figs. 1-2).

Lisianski Island: RT 641, RT 926 (on eastern beach).

Bangia fuscopurpurea (Dillwyn) Lyngbye, 1819: 83; Taylor, 1960: 293.

French Frigate Shoals: MSD 19476 (as a tuft near high tide line on La Perouse Rock). Det. by Dr. Maxwell S. Doty.

Centroceras apiculatum Yamada, 1944a: 42.

Pearl and Hermes Reef: RT 629 (Bird Island - on piece of coral), RT 908 (Southeast Island - beachdrift, epiphytic on *Microdictyon setchellianum* Howe).

Centroceras clavulatum (C. Ag.) Montagne *in* Durieu, 1846: 140; Dawson, 1954: 446, fig. 54h.

Necker Island: RT 955; *Kure Atoll*: MSD 19576E (Green Island).

Ceramium gracillimum Griffiths & Harvey *in* Harvey, 1846-1851, pl. 206.

French Frigate Shoals: RT 936 (East Island).

Ceramium mazatlanense Dawson, 1950b: 130, pl. 2 (figs. 14-15).

Lisianski Island: RT 643 (epiphytic on *Amphiroa fragillisima* (L.) Lamx.).

Falkenbergia hillebrandii (Bornet) Falkenbert = sporophyte generation of *Asparagopsis taxiformis* (Delile) Collins & Hervey; Feldmann & Feldmann, 1942: 89; Dawson, 1954: 414, fig. 25L.

Pearl and Hermes Reef: RT 623 (Bird Island).

Gelidium pusillum (Stackh.) Le Jolis, 1864: 139; Dawson, 1954: 420, figs. 31a-c.

Necker Island: RT 952; *Lisianski Island*: Ball (tuft on coral), RT 920 (on east beach); *Pearl and Hermes Reef*: RT 626 (Bird Island - juvenile forms covering small piece of coral).

Goniolithon frutescens Fosl., 1900: 9.

Pearl and Hermes Reef: Howe (in a meter of water).

Griffithsia ovalis Harvey, 1862, vol. 4: pl. 203; Abbott, 1946: 440, pl. 1 (figs. 1-4); pl. 2 (figs. 1-2).

Pearl and Hermes Reef: RT 910 (Southeast Island - beachdrift, epiphytic on *Microdictyon setchellianum* Howe). This sterile bead-like thallus about a centimeter long is tentatively listed under this species.

Haloplegma sp.

Kure Atoll: RT 984 (Green Island - beachdrift).

Herposiphonia sp. 1

French Frigate Shoals: RT 934A (Trig Island). At present, Dr. G. J. Hollenberg is studying all of these specimens of *Herposiphonia* from the Leeward group and will report on them later.

Herposiphonia sp. 2

Pearl and Hermes Reef: RT 625 (Bird Island - epiphytic on *Microdictyon setchellianum* Howe).

Herposiphonia sp. 3

Pearl and Hermes Reef: RT 906 (Southeast Island - beachdrift, epiphytic on *Microdictyon setchellianum* Howe), RT 912 (on rocks on west side of island).

Hypnea pannosa J. Ag., 1847: 14; Tanaka, 1941: 247, fig. 20.

Necker Island: RT 945 (forming entangled clumps).

Hypnea sp.

Lisianski Island: RT 925 (epiphytic on base of *Halimeda discoidea* Decaisne on eastern beach); *Pearl and Hermes Reef*: RT 919 (central lagoon - epiphytic on *Sargassum piluliferum* (Turn.) C. Ag.).

Jania capillacea Harvey, 1853: 84; Dawson, 1952: 116.

Necker Island: RT 951 (epiphytic on *Sargassum echinocarpum* J. Ag.); *Lisianski Island*: RT 923 (epiphytic on *Turbinaria ornata* (Turner) J. Ag. on eastern beach); *Pearl and Hermes Reef*: RT 907 (Southeast Island - beachdrift, epiphytic on *Microdictyon setchellianum* Howe); *Kure Atoll*: MSD 19576 (Green Island - epiphytic on *Turbinaria ornata* (Turner) J. Ag.).

Jania ungulata Yendo, 1902: 27, pl. 3 (figs. 7-8) and pl. 7 (fig. 8).

Pearl and Hermes Reef: RT 621 (Bird Island - epiphytic on *Turbinaria ornata* (Turner) J. Ag.).

Laurencia galtsoffi Howe, 1934: 39.

Pearl and Hermes Reef: Howe (on sand and coral in 3 meters of water).

Laurencia obtusa (Huds.) Lamx., 1813: 130; Yamada, 1931: 222, pl. 16 (figs. a-e) and pl. 17 (figs. a-c).

Necker Island: RT 940; *French Frigate Shoals*: RT 931 (Trig Island); *Pearl and Hermes Reef*: RT 616 (Bird Island), RT 904 (Southeast Island - beachdrift), RT 917 (in central lagoon); *Kure Atoll*: RT 983 (Green Island - beachdrift).

Laurencia sp. 1

Pearl and Hermes Reef: Howe (on coral sand in 7 meters of water).

Laurencia sp. 2

French Frigate Shoals: RT 935 (Trig Island).

Laurencia sp. 3

Kure Atoll: MSD 19576B (Green Island).

Liagora ceranoides Lamx. f. *pulverulenta* (C. Ag.) Yamada, 1938: 20; Abott, 1945: 156, figs. 8-9.

Pearl and Hermes Reef: RT 900 (Southeast Island - beachdrift). Male thallus about 11 cm in height, determined by Dr. I. A. Abbott.

Liagora farinosa Lamx., 1816: 240; Abbott, 1945: 163, figs. 14-15.

Laysan: MSD 19584 (determined as *L. kahukuana* Abbott in Tsuda, 1965). This specimen was sent to Dr. I. A. Abbott for verification and according to her, it is not *L. kahukuana* Abbott but falls within the circumscription of *L. farinosa* Lamx.

Liagora kahukuana Abbott, 1945: 149, fig. 2.

Laysan: Tanager Expedition (as *Liagora* sp. 2 in Tsuda, 1965). Determined by Dr. I. A. Abbott.

Liagora valida Harvey, 1852: 138, pl. 31a (figs. 1-5); Abbott, 1945: 160, figs. 12-13.

Laysan: Tanager Expedition (as *Liagora* sp. 1 in Tsuda, 1965). Determined by Dr. I. A. Abbott.

Liagora sp.

Pearl and Hermes Reef: RT 901 (Southeast Island - beachdrift). Upon examination of this male specimen, Dr. I. A. Abbott reports that it is very close to *L. valida* Harvey in internal structure but differs externally.

Lithophyllum sp.

Pearl and Hermes Reef: Howe (on broken corals in 1-2 meters of water).

Polysiphonia simplex Hollenberg, 1942: 782, fig. 18.

French Frigate Shoals: RT 934B (Trig Island). Species determination by Dr. G. J. Hollenberg.

Polysiphonia villum J. Ag., 1863: 941.

Pearl and Hermes Reef: RT 633B (Bird Island - on piece of coral). Det. by Dr. G. J. Hollenberg.

Porolithon sp.

Pearl and Hermes Reef: Howe (on broken coral in 1-2 meters of water).

Spyridia filamentosa (Wulf.) Harv. in Hooker, 1833: 337; Dawson, 1954: 444, fig. 54i.

Lisianski Island: RT 928 (on east beach); Pearl and Hermes Reef: RT 615 (Bird Island - epiphytic on Zonaria sp.).

Acknowledgments

The majority of the specimens reported here were collected under the auspices of the Pacific Ocean Biological Survey Program, Division of Birds, Smithsonian Institution, by Dr. Charles H. Lamoureux, Mr. C.R. Long, Mr. Alan L. Young, and Mr. Alan Anderson. The specimens are in the possession of the Department of Botany, University of Hawaii, with a second set being sent to the Smithsonian Institution.

The author is grateful to Dr. Isabella A. Abbott, Hopkins Marine Station, for her determinations of Liagora; to Dr. Francis Drouet, Academy of Natural Sciences of Philadelphia, for providing the determinations of all the blue-green algae; to Dr. William J. Gilbert, Albion College, for his verification of H. opuntia; and to Dr. George J. Hollenberg, Professor Emeritus of Biology, University of Redlands, for the species determinations of Polysiphonia.

Summary of Algal Collections

Table I summarizes the number of marine benthic algal species or varieties in each of the major divisions thus far recorded from each of the eight islands in the Leeward Hawaiian group. To date, no algal collections have been made from Gardner Pinnacles. By observing this table one can see the discrepancy between the number of algae from Laysan Island as compared to the number of algae from the other islands. More work on algal floristics is needed on these other islands, since Laysan is the only island on which a thorough collection has been made.

Table I. Number of marine benthic algae from the Leeward Hawaiian Group

Islands	Myxophyta	Chlorophyta	Phaeophyta	Rhodophyta	Total
Nihoa Island	0	1	1	0	2
Necker Island	1	8	3	5	17
French Frigate Shoals	1	2	1	6	10
Lisianski Island	0	6	2	6	14
Pearl & Hermes Reef	1	10	8	20	39
Kure Atoll	2	3	4	5	14
Midway Islands (Buggeln, 1965)	1	11	5	17	34
Laysan Island (Tsuda, 1965)	17	23	17	46	103

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No. 116

Reef studies at Addū Atoll, Maldive Islands

Preliminary results of an expedition to Addu Atoll in 1964

Edited by David R. Stoddart

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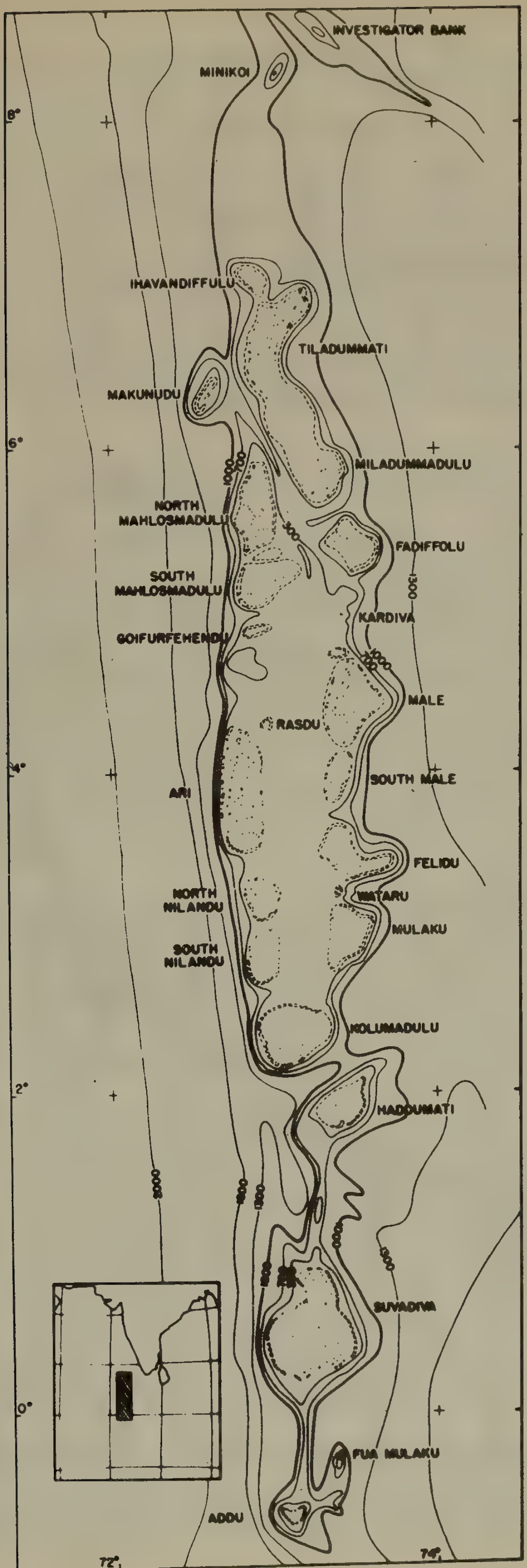
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Fig. 1. The Maldive Islands, after Farquharson (1936).

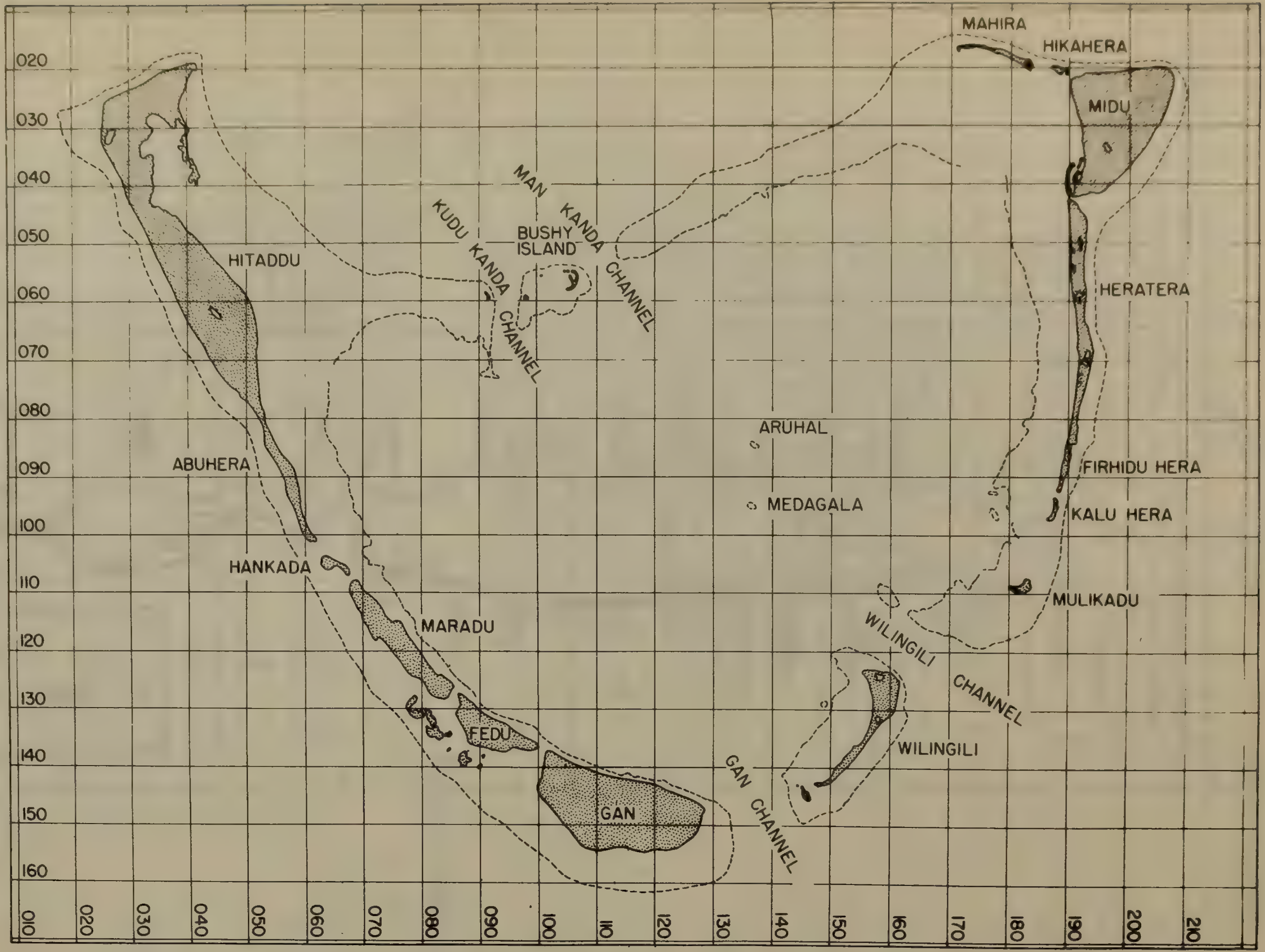
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Fig. 2. Addu Atoll, based on Admiralty Chart No. 2067; 1 kilometre location grid overlay.

I. INTRODUCTION

The Maldive Islands

The Maldive Islands proper (Fig. 1), between Ihavandiffulu and Haddumati Atolls, form a double chain of atolls, rising from a submarine plateau or ridge, 150-210 fathoms deep, 350 nautical miles long, and up to 70 nautical miles wide. The atolls are separated by channels which are deeper than the general plateau surface, and at the edge of the plateau the sea floor falls steeply to between 1000 and 1400 fathoms on the east side, and to 1300-2000 fathoms on the west side. The main features of the bathymetry were first recognized by Gardiner (1902, 1903-6), and subsequently confirmed by Farquharson (1936).

Both to north and south of the main plateau the bottom topography is less clear. Minikoi, in the north, is linked to the main Maldive plateau by a shelf at 700-900 fathoms. In the southern Maldives, the plateau may be interrupted between Haddumati and Suvadiva Atolls at about 900 fathoms. Between Suvadiva and Addu Atolls the plateau does not seem to exist: the minimum sounding midway between the two atolls is 845 fathoms, rising to 654 fathoms 12 nautical miles north of Addu, and most of the soundings range from 1000 to 1200 fathoms. The existence of a deep ridge seems clear, however, for on either side of a line joining the two atolls, at depths of about 1000 fathoms, the floor falls to depths of 1300-1500 fathoms on the east side, and to 1400-2000 fathoms on the west. The relationship of Fua Mulaku Island, between Addu and Suvadiva, to this ridge is unknown.

South of Addu, between the Maldives and the Chagos Archipelago, soundings are few. Immediately south of Addu, depths of 1200 fathoms are recorded, increasing to more than 1800 fathoms at 3°S. This suggests that the Mid-Ocean Ridge, extending northwards to the Chagos at about 67°E longitude, and swinging northwestwards from there towards the Gulf of Aden, thus forming the Carlsberg Ridge with depths of about 1000 fathoms, does not continue uninterruptedly into the Maldives (Heezen 1962; Heezen and Ewing 1963, 396; Heezen and Tharp 1964). Recent work on the structure of the Indian Ocean has concentrated on the Carlsberg Ridge, and does not make its relationship with the Maldives ridge clear. At the 2000 fathom level the Maldive Ridge is continuous with the Carlsberg and Mid-Ocean Ridges: to the east of the Maldives Ridge the ocean floor lies at more than 2000 fathoms, between the Maldives and Carlsberg Ridges it averages 2400 fathoms (reaching 2600), and s.w. of the Carlsberg Ridge the floor averages 2700 fathoms and in places reaches more than 2800 fathoms. Farquharson (1936) uses the 1300 fathom isobath to delimit the Maldives Ridge, thus including Minikoi and Addu; most of the Maldives atolls are connected at the 300 fathom level.

Most observations on the structure of the Maldives have been speculative. Darwin (1842, 110), followed by Davis (1928, 527-532), suggested that subsidence of an island like New Caledonia, with reef upgrowth, could form such a double chain of atolls. Gardiner (1902, 1903) believed that the main Maldives plateau was formed by current erosion, and that the atolls themselves were subsequently formed by the growth of deep- and later shoal-water organisms on this formation. During the John Murray Expedition, Glennie (1936) made gravity readings at several stations, including Midu Island, Addu Atoll. These showed a strong negative anomaly along the whole Maldives ridge, which Glennie interpreted as indicating a thickness of several thousand feet of reef limestone. Magnetic anomaly studies carried out by H.M.S. Owen in 1962 demonstrated small field changes in the Maldives and Laccadives, which were interpreted as indicating the presence of a continental basement (Gaskell and others, unpublished data). In contrast to the mid-ocean ridge characteristics of the Carlsberg Ridge (high heat flow, seismicity, vulcanicity (Hill and others 1964)), the Maldives and Laccadives area is notably aseismic.

Reef studies in the Maldive Islands

Several large expeditions have visited the Maldive Islands reefs, yet paradoxically they remain one of the least known groups of atolls. Unlike Pacific atolls, the Maldive Islands have been known to the west since medieval times. Ibn Battuta visited the islands in 1327 and gave the first recognisable account of Maldivian life (Ibn Battuta 1829, 1854-8, 1890, 1929). In 1602 François Pyrard de Laval was shipwrecked in the Maldives, lived there for five years, and wrote a spirited account of topography, vegetation, and native life (Pyrard 1887-1890). At this time Portuguese influence in the islands was great, since the Maldives lay across the shipping route from Europe to the Far East. Scientific investigation properly began in the Maldives with Commander R. Moresby's hydrographic survey for the East India Company in the 1830s, a survey which for most atolls forms the basis of current charts. Moresby's remarkable survey of so large an area resulted in charts of great elegance, but his vessel carried no naturalist, and he does not appear to have concerned himself with reef physiography or fauna. Apart from his own brief memoir (Moresby 1835), and some botanical and general data by other officers (Christopher 1841, Horsburgh 1832, Owen 1832, Young and Christopher 1844), the only published conclusions on the reefs of the Maldives from this survey are those of Darwin (1842), based on communication with Moresby himself. Moresby's two nautical memoirs, on the islands of the Indian Ocean, and on the Maldives, remain in manuscript.

The major advance in scientific knowledge of the Maldive Islands dates from the expedition led by J. Stanley Gardiner of Cambridge University to the Maldives and Laccadives in 1899-1900. Gardiner's work was mainly zoological, and his collections, based on extended stays at Minikoi and South Male Atolls and brief excursions through the whole group, were published in two large quarto volumes and a series of papers. Gardiner himself contributed studies of reef and island physiography and speculated on the coral reef problem and the origin of the Maldives (Gardiner 1900a, 1900b, 1901b, 1902, 1903a, 1903b, 1906d, 1930, 1931), as well as working up some groups of scleractinian corals (Gardiner 1906b, 1906c, 1909, 1929). In spite of his reef experience in the Western Pacific, however, Gardiner was no physiographer, and many of his ideas on the Recent history and development of the reefs and islands must be discounted. His major contribution lies in the systematic lists of land and marine fauna (Gardiner 1903-6), and in his botanical collections (land flora: Willis and Gardiner 1903; marine flora: Foslie 1903, Barton 1903), which until recently remained unique. It is difficult to obtain from Gardiner's work any precise idea of the structure of modern Maldivian reefs, or of the distribution and relative importance of corals and other reef organisms. A number of groups, including the genus Acropora, also remained unmonographed. Without Gardiner's work, however, our knowledge of the Maldives would be sparse indeed. Gardiner was followed by Alexander Agassiz, who spent two months in 1901-2 cruising through the whole archipelago, making a large number of shipboard observations and deductions (Agassiz 1902a, 1903). Many of Agassiz's plates are of interest, but in general his work is of small value compared with that of Gardiner.

The major event of the inter-war period was the John Murray Expedition 1933-34, led by R. B. Seymour Sewell. Sewell, who had already published on the reefs of the Indian Ocean (Sewell 1932, 1935), carried out gravity surveys and deep soundings in the Maldives (Glennie 1936, Farquharson 1936) and published physiographic descriptions of Addu and Goifurfehendu Atolls (Sewell 1936a, 1936b). Like Gardiner, Sewell was a zoologist, not a marine geologist, and his chief work was on the Copepoda. His physiographic work, while of great value, contains many untenable speculations. Taken together, however, Gardiner's and Sewell's expeditions provide the greater part of our knowledge of the atolls and their reefs. Subsequently, Gardiner led the Percy Sladen Trust Expedition to the Indian Ocean in 1905, which, while not directly concerned with the Maldive Islands, led to Matthai's studies of the Indian Ocean corals (Matthai 1914, 1924, 1928), including many of Gardiner's type specimens from the Maldives. The reports of the Percy Sladen Expedition contain much material relevant to the study of the Maldive Islands (Gardiner 1907-1936).

The pre-1945 literature is largely completed by reference to a series of reports by H. C. P. Bell (1882, 1921, 1940) which, though largely historical, include much topographic data and information on flora and native names of plants. Gray (1878) compiled a vocabulary. A few expeditions touched at the Maldives, including the Deutschen Tiefsee Expedition (Chun 1905) and the S.M.S. Planet (Lübbert 1909). A full bibliography is given by Sachet and Fosberg (1955), and also in this paper.

The limitations of these data became apparent with the increasing number of Pacific reef studies after 1945. Emphasis in these on reef distribution, ecology and sedimentology, rather than on systematics, gave reef studies new impetus. When Wiens summarised postwar work in 1962, therefore, the reefs of the Indian Ocean received virtually no mention, although the Maldives include some of the largest atolls on earth, and many have unique characteristics unknown in Pacific and Caribbean atolls. The need for further studies of Maldivian reefs became more apparent, but for political reasons few scientists were able to visit the area. The Xarifa carried out systematic studies in 1957-8, under Hans Hass, which are in the course of publication (Hass 1961, 1965; Eibl-Eibesfeldt 1964); Hass's own contributions on marine geology (Hass 1962a, 1962b, 1963) are largely speculative. Fosberg (1956) briefly visited Male in 1956, and published a revised and augmented version of Trimen's (1896) and Willis and Gardiner's (1903) flora. Deraniyagala (1956) published the results of ecological collecting in 1932, and Kohn (1964a) has published molluscan and general notes following visits to the southern atolls in 1957. Both the Te Vega and the Anton Bruun have visited the Maldives in connection with the International Indian Ocean Expedition, but results have not yet been published, and in general political conditions made extensive work in the Maldives during this Expedition impossible.

Present expedition

An expedition was, therefore, first planned in 1962, to visit the Maldive Islands and to carry out on a small scale reef studies similar to those carried out in the Pacific since 1945, to provide data on topography, sedimentology, marine geology, and ecology of the reefs, reef flats, islands, and other environments. It was hoped to work at either Male or Kolumadulu Atolls, but this proved politically impossible, and finally permission was given for a small party to work at the Royal Air Force Staging Post at Gan Island, Addu Atoll, southern Maldives, in mid-1964. For political reasons work on islands other than Gan and part of Hitaddu was impossible, but traversing and sampling the lagoon and its reefs was allowed. The expedition thus came to concentrate on reef and island environments around Gan and, to a lesser extent, Hitaddu Islands.

The expedition was led by Dr. D. R. Stoddart, Department of Geography, Cambridge, who concentrated on topography, sedimentology and marine geology of reefs, reef flats and island beaches. Dr. P. Spencer Davies, Department of Zoology, Glasgow University, collected marine invertebrates and was in charge of aqualung work on the reefs. Mr. D. C. Sigee, Department of Botany, Cambridge University, collected land plants and marine algae, and Mr. A. C. Keith of the Department of Geography, Cambridge University, assisted with the surveying and sediment sampling programmes. The detailed reef transects were carried out jointly by all members under the direction of Dr. Davies. The party arrived at Gan on 1 July 1964, and remained until September 10. The collections and other data collected by the expedition will take some years to work out, and this report is hence of a preliminary nature. The main collections were sent for identification as follows: land plants, Dr. F. R. Fosberg; marine algae, Mr. R. Tsuda; stony corals, Dr. J. W. Wells.

Previous work at Addu Atoll

Being remote from the centre of Government in Male, Addu Atoll (Fig. 2) has been visited only briefly by most of the expeditions working in the Maldives. The first detailed examination of the atoll was made by Commander R. Moresby and Lieut. F. T. Powell in 1836, their small scale chart being published in 1839. Moresby's manuscript Nautical directions for the Maldive Islands (no date, c. 1837) contains an extended account of Addu (p. 39-46), reproduced here as Chapter VI. The first scientific account is that of J. Stanley Gardiner, who spent 11-15 April 1900 at Addu, making soundings, taking 14 dredge hauls in the lagoon, and collecting fauna and flora, chiefly at Midu and Maradu Islands. For Gardiner's description of Addu, with a sketch map, see Gardiner 1903a, 10; 1903b, 150-151; Willis and Gardiner 1901, 78-80; and other references cited in this report. Alexander Agassiz spent two days at Addu in January 1902, published brief notes on Midu, Wilingili and Gan Islands, and took issue with Gardiner on lagoon floor sedimentation (Agassiz 1903, 145-148). Subsequently H.C.P. Bell visited Addu in his third tour in the Maldives, spending 10-15 February 1922 at Gan and Hitaddu Islands, describing their historical remains (Bell 1940, 115-121).

During February-April 1923, Commander F. H. Daugleish, R.I.M.S. Investigator, carried out a survey of Addu Atoll at a scale of 1:18,136, making approximately 18,000 soundings in the lagoon and the reef channels. Until the post-1945 work in the Marshall Islands this was the most detailed atoll chart in existence, but for military reasons it remained classified until 1964. The published chart of Addu remained that by Moresby, with some corrections, until the current Admiralty Chart No. 2067, based on Daugleish's but with a greatly reduced number of soundings, was published in 1957. Land topography on Daugleish's chart was sketchy, and in some cases had changed considerably since 1923, so that the Daugleish chart was republished in 1964, with land topography and outer reef detail from aerial photography of 1958 and 1960. With the establishment of the Gan Staging Post, a number of minor hydrographic surveys have been carried out to supplement Daugleish's chart.

Addu was visited by the John Murray Expedition 1933-34. Soundings (Farquharson 1936) and gravity profiles (Glennie 1936) were made at Addu, and Sewell (1936a) contributed a general account of the whole atoll. This for the first time described the reefs and reef-flats, added additional lagoon soundings to Moresby's and Gardiner's charts, and included notes on Midu, Heratera, and, more briefly, the other islands. There has been little opportunity for scientific work at Addu since Sewell's expedition. The ornithologist Phillips has recorded bats, amphibians and reptiles in the Maldives, including Gan (Phillips 1958a, 1958b, 1958c, 1958d, 1963; Phillips and Sims 1958a, 1958b). The conchologist Kohn, of the Yale Seychelles Expedition, spent a week at Addu in October 1957, visiting Gan, Hitaddu and Wilingili Islands, recording mollusca (Kohn 1964b). Hans Hass with the Xarifa Expedition visited Addu in early 1958 (Hass 1961, 34-63, 80-85; Eibl-Eibesfeldt 1964), and some systematic reports are being published (Scheer 1960a, Gerlach 1960, 1961).

Acknowledgments

For the opportunity to work at Addu Atoll we particularly wish to thank the Commonwealth Relations Office, London; the Ministry of Defence (Air), London (which also provided transportation to and from Gan for the four members of the party); and Wing Commander G. Moss, A.F.C., Royal Air Force, Gan, for his kindness in allowing us to work on the island, supplying us with quarters, and allowing us to use the facilities of the Officers' Mess. To many members of the Service and civilian personnel at Gan our debt is considerable, but we would like to thank especially Ft. Lt. D. Hunter and Mr. E. Denis of the Gan Sub-aqua Club for help in underwater work and for the use of the launch Victoria. The expedition was made possible by generous financial help from a variety of sources, much of which was sought at a very late stage. We wish to record our thanks to the following for help in this way: The Royal Society, the Goldsmiths' Company, Shell International Petroleum Limited, the Vaughan Lewis Fund of Cambridge University, the University of Glasgow, the Carnegie Trust for the Universities of Scotland, British Petroleum Company Limited, the Permutit Company Limited, Middlesex Education Committee, Glasgow Breweries Limited, and George Ballantine and Son Limited. We also thank the British Museum (Natural History) for the loan of collecting equipment, and the following organisations for supplying equipment at reduced rates: Rank Precision Industries Limited, Wallace Heaton Limited, Lillywhites Limited, Sangamo Weston Limited, Submarine Products Limited, and Kodak Limited.

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Present report

This report can only be preliminary, since most of the collections have yet to be worked up. It is intended only as an outline of the work which took place, and to serve as a framework for future reports. The conclusions given here on the geomorphology and vegetation of Addu Atoll are, therefore, provisional. The report provides a general account of Addu Atoll, with a more detailed consideration of some aspects of its geomorphology and its vegetation. Work on the zoology of the reefs will be published at a later date.

Unpublished Crown-copyright material in the India Office Records transcribed in Chapter VI appears by permission of the Secretary of State for Commonwealth Relations. The bottom topography of Addu Atoll lagoon in Figure 10 is derived from Admiralty Original Document No. C 9155, with the permission of the Hydrographer of the Navy, and the reef and island topography, based on air photographs, is reproduced from Chart No. 2067 of 1964, with the permission of the Controller of H.M. Stationery Office and of the Hydrographer of the Navy.

II. CLIMATE AND MARINE ENVIRONMENT

Climate

This section briefly summarises data on climate and marine environment of Addu Atoll. Gardiner (1903, 20-21, 25) commented on the climate as observed in 1900, and stressed the variability of winds, Addu lying too far south for the monsoon reversals to be strongly felt. Gardiner estimated annual rainfall at 150 inches (too high, judging by recent records). Agassiz (1903, 145) and Sewell (1936a, 65) made similar observations. Addu differs from the northern Maldives (a) in its greater total rainfall, and its less seasonal nature; (b) in the weakened effect of monsoon wind reversals; and (c) in the absence of typhoons, which originate in the Laccadive area and travel northwards. The contrast with trade wind atolls in the Pacific and the Caribbean is marked.

Instrumental records began to be kept in the Maldive Islands during World War II. Wells (1948) reported 4 years of observations at Male, and Newnham (1949) compiled wartime records at Addu Atoll for the period September 1942 to December 1945. With the establishment of the R.A.F. Staging Post at Gan, recording was resumed in October 1957 for temperature and rainfall and in June 1960 for winds. The data to 1964 have been analysed by the Meteorological Centre at Gan, and the following account is abstracted from their summary:

"The weather experienced differs little from that of the surrounding Indian Ocean but the heating of the land by day and its cooling by night causes an average diurnal variation of temperature of around 10°F. Only small variations occur in the surface pressure and these are masked by the diurnal pressure variation which has a range of about 4 mb with pressure maxima at about 1000 and 2200 and minima at 0400 and 1600 hours local time. Temperature and humidity show also only a small annual variation being controlled largely by the warm water of the Indian Ocean. It is unusual for the sky to be either overcast or free from cloud for a day or more at a time, and much of the cloud is of the convectional type, ranging from fairweather cumulus to massive cumulonimbus. During rainier periods there is often a background of Altostratus and Cirrostratus. Rainfall averages around 90 inches per year, the highest total so far recorded being 118 inches and the lowest 74 inches. Visibility is usually very good except when rain is falling. Occasionally in very heavy rain it is reduced to less than 1000 yards. Strong winds or gales are relatively rare, although Westerly winds during a wet spell blow rather strongly for several days. However, during wet spells squalls of up to 70 kts have been experienced. Surface winds in January from between WNW and NNE become mainly North or Northeast in February (cf. Fig. 3, where wind data are plotted as monthly wind roses). In March winds are evenly distributed between WSW and NNE, but in April become mainly Westerly. The

Westerly winds persist throughout May, then change in June to blow from between Southwest and Southeast. Throughout July and August winds are between South and Southeast, then change to a more Southwesterly direction in September; October and November see the re-establishment of the Westerly, but in December winds become more variable, being distributed between WSW and NNE.

"The weather at Gan is controlled by the migration North and South with the sun of the belt of Equatorial Westerlies unique to this area of the Indian Ocean, which lie between the Northeast Trades of the Northern Hemisphere and the Southeast Trades of the Southern Hemisphere. Along the boundaries between these wind regimes lie zones of convergence which give rise to unsettled rainy weather. The boundary between the Westerlies and the Northeast Trades is called the Northern Shear Line, and that between the Westerlies and the Southeast Trades the Southern Shear Line. Almost invariably prolonged spells of unsettled weather are associated with oscillations north and south over Gan of one or the other of these shear lines.

"Roughly the weather at Gan divides into five main types, as follows:

Type 1. Northeast Trade type with the Northern Shear Line south of Gan. The surface wind is mainly northeasterly and the weather fair but sometimes showery.

Type 2. Disturbed Westerly Type A associated with the Northern Shear Line oscillating north and south over the area. The surface wind is mainly Westerly and the weather unsettled, with periods of heavy rain, accompanied at times with squalls of between 40 and 70 kts.

Type 3. Settled Westerly type with the shear lines well north and south of Gan. Surface winds are westerly and the weather is fine.

Type 4. Disturbed Westerly Type B associated with the Southern Shear line oscillating north and south over the area. The surface wind is westerly and the weather unsettled, with periods of heavy rain accompanied at times with squalls of between 40 and 70 kts.

Type 5. Southeast Trade Type with the Southern Shear Line north of Gan. Surface winds are southeasterly. The weather is mostly fair but spells of unsettled weather are also likely with periods of rain and fresh southeasterlies of up to 30 kts.

"January and February usually have either Type 1 or 2. March and April usually have either Type 2 or 3. May, June and July usually have Type 3, 4 or 5. August and September usually have Type 5. October and November usually have Type 2, 4 or 5. December usually has Type 2.

"To complete the summary mention should be made of periods of light and variable winds which occur from time to time in any month. They usually last from 2 to 5 days, but there have been exceptional periods of up to 12 days. The weather is fine but sometimes showery. Showers when they occur may be heavy and prolonged, but severe squalls of wind are usually absent."

Figure 4 shows annual temperature data at Gan, October 1957 - September 1962. The monthly figures vary less than 3°F throughout the year, which is considerably less than the diurnal variation. Figure 5 plots mean monthly rainfall at Gan for the period October 1957 - June 1964, together with the records for each month in this period and for the period February 1944 - February 1945. The figures show a considerable range in each month, from a monthly minimum of 0.60 inches to a monthly maximum of 18.75 inches (mean 7.91 inches). There is no clear seasonal pattern, except that February and March tend to be drier than the rest of the year.

Currents and tides

Marine currents in this area are variable with the monsoon circulation, but under the influence of the Equatorial countercurrent the predominant current direction appears to be eastward of northeastward. "Current observations are, however, scanty in this region, but it is probable that marked variations of current direction occur" (West Coast of India Pilot, 1961, 57).

Tidal variations are referred to the standard station at Madras. Low water springs stand at 0.6 feet and high water springs at 3.8 feet, an extreme range of 3.2 feet. Low water neaps stand at 1.7 feet and high water neaps at 2.6 feet (Admiralty Tide Tables, 2 (1965), Atlantic and Indian Oceans). A predicted curve for part of 1964 is given in Figure 6. According to the West Coast of India Pilot, at Addu Atoll "the flood stream sets strongly into the lagoon through Wilingili channel and out of the lagoon through Gan channel, but the ebb stream sets out of the lagoon through both these channels; thus whereas in Wilingili channel there is a reversal of the tidal stream with the change of tide, in Gan channels the stream sets continuously out of the lagoon. In Kudu Kanda channel, the tidal streams set into the lagoon with the flood tide and out of it with the ebb, but in Man Kanda channel, the tidal streams set continuously out of the lagoon" (Hydrographic Department 1961, 61).

Continual wave action on the reef edge, together with tidal variation, sends a continuous sheet of water across the reef flats, particularly between islands. In the channel between Gan and Fedu Islands, on the Addu reef flat, current measurements with fluorescein and with floats at high water on 24 August 1964 gave values of 1-2 kts off the west end of the runway, and of 1.5 kts lagoonward of the causeway between the two islands.

Sea temperature and salinity

Sea temperatures are approximately 28-29°C (82.4-84.2°F) throughout the year. H.M.S. Owen recorded 28.1-28.8°C (82.6-83.8°F) in this area in early 1962, and Agassiz a surface temperature of 27.8°C (82°F) and bottom temperature of 27.8°C (82°F) at 22 fathoms in Addu lagoon in January 1902. Temperatures measured during the Gan lagoon reef transect work in 1964 varied from 27.0 to 28.0°C. On the lagoon reef slope temperatures were isothermal to depths of at least 80 feet, but they tended to be more variable on the reef flat. The following tables summarise temperature and salinity data recorded by Dr. Davies on the lagoon reef transect I in 1964:

(a) Variation in temperature and salinity with depth in lagoon reef transect I.

Depth ft	Temp. °C	Salinity °/oo
Surface	28.0	34.7
10	28.0	34.7
20	28.0	34.7
30	28.0	34.7
40	28.0	34.7
50	28.0	34.7
60	28.0	34.7
70	28.0	34.7
80	28.0	34.7

(b) Variation in temperature and salinity over the lagoon reef flat in transect I during one tidal cycle, after moderate rain with light wind from the north. Readings taken at surface and at bottom at inshore, mid-flat and reef edge locations at LWST and HWST on 23 August 1964.

0900 hrs, LWST

Zone	Sample	Temperature °C	Salinity °/oo
Inner	surface water	27.0	33.8
	bottom (2 ft below)	27.5	33.8
Mid-flat	surface	28.0	34.8
	bottom (3 ft below)	28.0	34.7
Reef edge	surface	27.5	34.7
	bottom (6 ft below)	28.0	34.4

1500 hrs, HWST

Zone	Sample	Temperature °C	Salinity °/oo
Inner	surface	28.0	33.9
	bottom	28.0	33.9
Mid-flat	surface	28.0	34.1
	bottom	28.0	34.1
Reef-edge	surface	28.0	34.1
	bottom	28.0	34.1

These data show a slight salinity gradient across the reef flat from land to sea on the lagoon reef. A higher gradient was found on the seaward flat, particularly after heavy rainfall, as shown in the following determinations by Dr. Davies. They may be compared with normal sea salinities of 33.8-34.4 ‰ in this area, determined by H.M.S. Owen in 1962.

Sample (100 metre intervals from shore to seaward edge)	Salinity °/oo	
	Shortly after LWST	Following heavy rain
1	26.3	16.7
2	31.7	31.5
3	30.8	31.5
4	31.2	31.5
5	31.0	31.6
6	30.8	31.6
7	34.1	32.0
8	34.3	33.8
9	34.4	34.7
10	34.5	34.7
11 (reef edge)	-	34.7

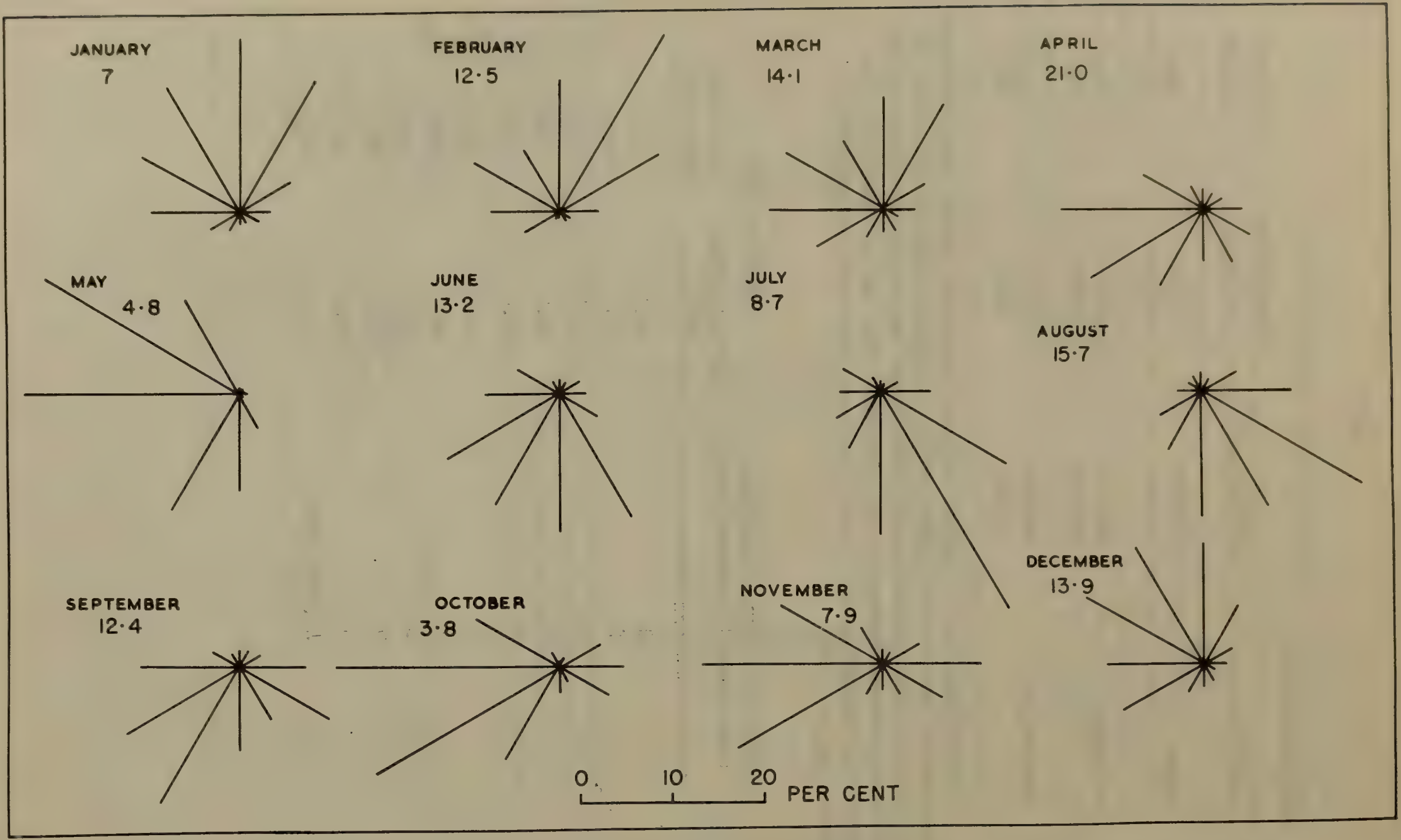


Fig. 3. Mean monthly wind directions at Gan Island, 1960-1964, based on data supplied by the Meteorological Service, Gan. Figures refer to percentage calms.

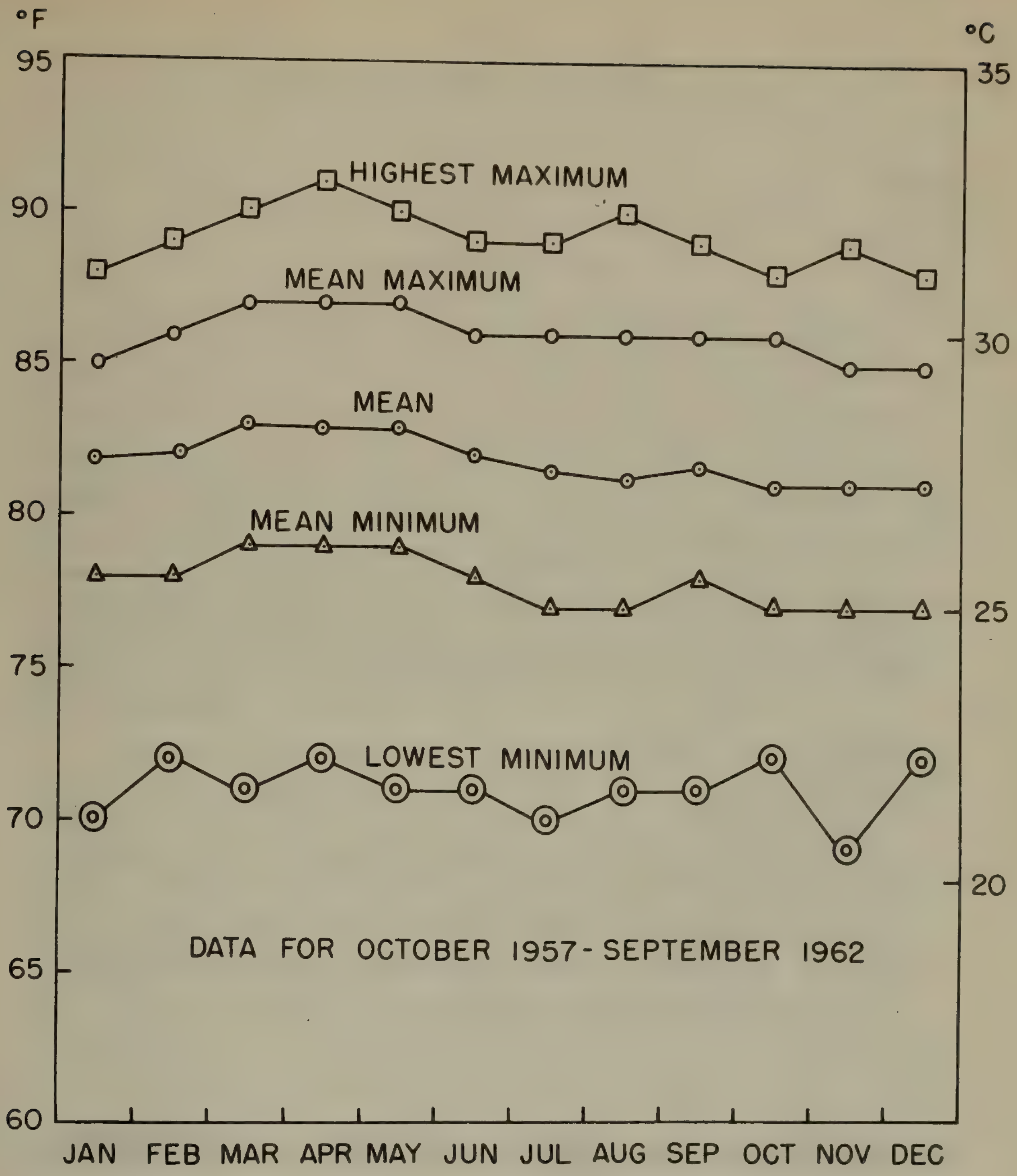


Fig. 4. Monthly temperatures at Gan, October 1957-September 1962, based on data supplied by the Meteorological Service, Gan.

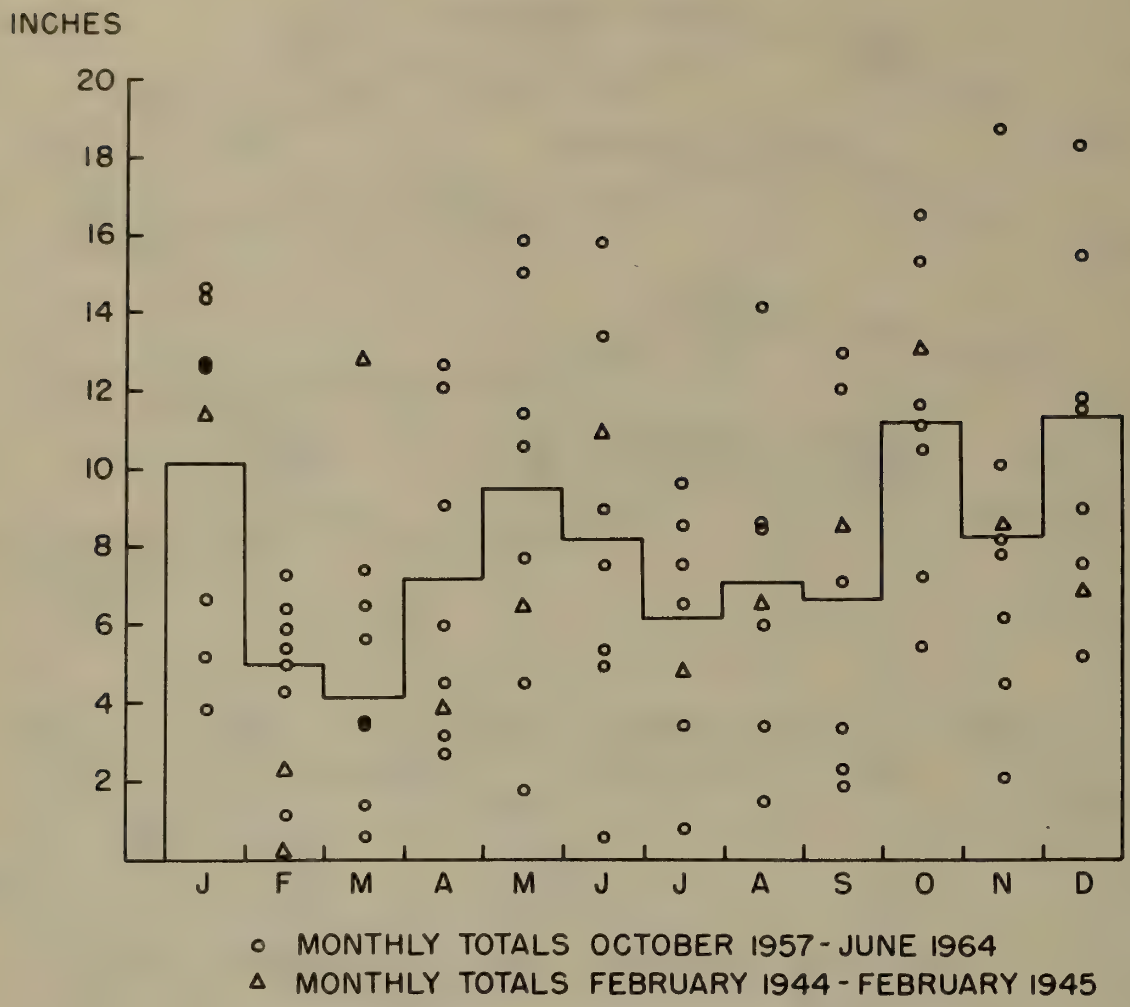


Fig. 5. Range of rainfall and mean monthly rainfall at Gan, October 1957-June 1964, based on data supplied by the Meteorological Service, Gan.

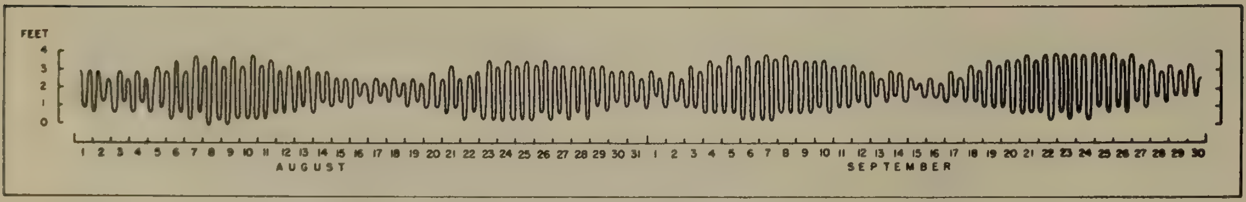


Fig. 6. Predicted tides for August and September 1964, based on data supplied by the Marine Craft Section, Gan.

III. GEOMORPHOLOGY OF ADDU ATOLL

by

D. R. Stoddart, P. Spencer Davies and A. C. Keith

A. General description

Addu Atoll, latitude 0°38' South, longitude 73°10' East, is the southernmost atoll in the Maldive Islands, separated from the next nearest atoll to the north, Huvadu or Suvadiva Atoll, by the 45 mile wide Equatorial Channel. The next nearest atoll to the south is Salomon Atoll, Chagos Arthipelago, 320 miles distant. Addu itself (Fig. 2) is one of the smallest of the Maldive atolls, measuring 28.4 km (17.6 miles) in maximum dimension (NW to NE points), and 16.5 km (10.2 miles) in the transverse direction. The atoll may be termed semi-circular or triangular: the south-facing reefs are broadly convex, the northern reef concave. The shape may be approximated to that of a triangle, apex southwards, with a base of 28 km between the northwest and northeast points, and sides of 25 km. Shape measurements by several methods give values for Horton's F number of 0,604, for Miller's Circularity Ratio of 0.754, for Schumm's Elongation Ratio E of 0.895, for Boyce and Clark's Radial Line Index of 28.54, and for the Ellipticity Index of 1.3 (Stoddart, in press).

The total area of the atoll is approximately 60 square nautical miles, or 6.5 on Haggett's G scale (Haggett et al. 1965). Of this, no less than 41% consists of reef flat and islands. The peripheral reefs of the atoll are broad, ranging from 700 metres on the north side to 1900 metres on the southwest; maximum widths of up to 2900 metres are found on the northwest projection. The reefs are continuous except for two gaps in the centre of the southern reef (Gan Channel, Wilingili Channel) and two in the centre of the northern reef (Kudu Kanda Channel, Man Kanda Channel). Gan Channel, which is buoyed, is 950 metres wide with a sill depth of 9-10 fathoms; Wilingili Channel, 750 metres wide, has a sill depth of 21-31 fathoms. In the north the channels are narrower: Man Kanda, which is buoyed, is 350 metres wide with a 13-18 fathom sill; Kudu Kanda is 250 metres wide, with a 13-19 fathom sill. All the peripheral reefs are of simple linear form, and lack the ring-shaped faros so well developed in the northern Maldives. Little is known of the detailed topography of the atoll slopes. The John Murray Expedition ran a profile from the northeast corner of the atoll, recording a depth of 1000 fathoms within 4.5 miles in the easterly direction (mean slope 14°10') and within 5 miles to the northeast. Their soundings also indicated a ridge extending northeastwards towards Fua Mulaku, shown by soundings of 590 and 654 fathoms (Farquharson 1936, Plate 6). H.M.S. Modesta, sounding out of Gan Channel in 1956, recorded 1069 fathoms 1.5 nautical miles southeast of the Wilingili reef edge, giving a mean slope of 35°.

The atoll lagoon is elliptical, with its axis trending ENE-WSW. It has a maximum length of 11.7 km and breadth of 9 km. Unlike the northern Maldive atolls, such as North Male and Ari, there are few knolls or patch reefs in Addu lagoon. The two most conspicuous patch reefs are near the lagoon centre, named Medagala and Aruhal, on which waves break even in calm weather. Medagala and two smaller patches near the west side of the lagoon are buoyed. Small reef patches and knolls are more profusely developed in the extreme northwest and northeast corners of the lagoon, but elsewhere the lagoon reef slope falls steeply to the lagoon floor. The maximum lagoon depth is 43 fathoms, comparable to that of the much larger Huvadu Atoll and considerably deeper than that of the larger atolls in the northern Maldives (cf. Biewald 1964, 354).

Islands occupy approximately 20% of the peripheral reef flat of the atoll by area, and no less than 65% of the seaward reef edge is backed by land. The only extensive reef sector without land is the concave northern reef. There are large villages on two of the islands, Midu and Hitaddu, and the settlement formerly located on Gan Island has been relocated on Fedu following the 1960 Agreement between Britain and the Maldivian Government. An airstrip was operational on Gan Island during the Second World War, when the deep channels and lagoon of Addu proved of naval value (the Queen Mary has anchored here). Following the Agreements of 1953 and 1960 the Maldivian Government has made certain scheduled territories (Gan Island and part of Hitaddu Island) available for use as a Royal Air Force Staging Post. Development of this Staging Post has involved the construction of a new runway and facilities, with personnel quarters on the northwest side of the island.

The population of the atoll was 4664 in 1931 and 5686 in 1946 (Didi 1949); in 1963 it was 8235. For a fairly detailed general account, see the West Coast of India Pilot, tenth edition (1961, p. 57-62), together with the more scientific papers cited in this report.

To aid in location an arbitrary 1000 metre grid was laid down on the Admiralty Chart (No. 2067) of Addu, related to the earth graticule in that the 0°40' S latitude line and the 12 km S grid line, and the 73°10' E longitude line and the 12 km E grid line are coincident. This basic 1000 metre grid shown in the figures in this report may then be subdivided to give locations to the nearest 10 metres, easting before northing in each point reference. The grid, with a 100 metre interval, was also superimposed on an enlarged vertical air photograph of Gan to aid location referencing in the field. All reef flat and lagoon locations were obtained by horizontal sextant angles on fixed island points, and then reduced to grid coordinates.

B. Peripheral reefs

The most detailed descriptions of the Addu reefs are those of Sewell (1936a, 69-72, 87-92), who divided the reef area into reef platform, outer reef and inner reef. Gardiner (1903, 317-321, 416) briefly comments on the reefs, stating that "the coral growth, taken as a whole, in Addu lagoon is most extraordinary, and in vigour quite surpasses anything in my experience elsewhere either in the Maldives or in the Pacific Ocean" (1903, 319). Most of his remarks on reef characteristics, however, are phrased in general terms. Agassiz (1903, 148) doubted whether the coral growth on the lagoon reef slopes of Gan was as vigorous as Gardiner implied. Kohn (1964a) gives a brief description of the reef flat and reefs at Hitaddu and Gan. Eibl-Eibesfeldt (1964, 38-39) gives a schematic section of the reefs of a Maldivian atoll, and his zonation is followed here (Fig. 7). Figure 8 gives in diagrammatic form cross-sections of the peripheral reefs at Gan (B) and Hitaddu (A) Islands, to show contrasting conditions at these two locations. Peripheral reef characteristics are treated under the following headings: (i) seaward reefs and slope, (ii) seaward reef edge (algal platform), (iii) seaward reef flat, (iv) northern reefs--Midu side, (v) lagoon reef flat, reef and slope.

(i) Seaward reefs and slope

Little is known of the seaward reefs of Addu, except from air photographs, though Davies and Keith inspected the seaward reef slope by diving at Gan and Bushy Island. The 1958 aerial photography shows spur-groove formation well-developed along the reef front along the whole of the convex southern reefs from Hitaddu to Midu, but not along the northern reefs, the lagoon reefs, or in the channels. Along most of the southwest reefs the lineations are approximately 100 metres long, or less; but off Wilingili they reach 250 metres, and off Mulikadu, north of Wilingili Channel, they reach a maximum length of 300 metres. The depth to which the lineations extend is unknown; Davies and Keith report no apparent trace of lineations on the seaward slope off Gan in depths of 7-16 fathoms. They also report a fairly gentle bottom slope, suggesting that at some point, perhaps 400-500 metres outside the breakers at Gan, the bottom slope increases rapidly and falls to great depths. Air photographs indicate that the reef front outside the breakers is steeper or the reef front terrace narrower round most of the rest of the atoll perimeter than at Gan. There is no data on the area immediately outside the breakers, which Wells (1957, 618) terms the innominate zone.

Hass (1961, 60) and Eibl-Eibesfeldt (1964, 37) describe an abrupt increase in bottom slope to form a "reef wall" at the foot of the more gentle reef slope outside the breakers on the seaward sides of Maldivian atolls. Undercutting at the base of this reef wall forms "Grotte" or "Höhle" at depths of 25-135 metres (14-19 fathoms). Hass ascribes this undercutting to low-level marine erosion during a Würm glacial low sea level at -30 metres (16.4 fathoms). Main Würm sea levels, however, were probably in excess of -100 metres (Donn, Farrand and Ewing 1962), and stillstands at the -30 metre level may be connected with the Allerød or similar oscillations. Whether these brief Holocene stillstands (Fairbridge 1961) were long enough to cut Hass's features is debatable. Similar undercutting was unfortunately not observed during the 1964 expedition.

An attempt was made by Davies and Keith to investigate the structure of the seaward reef slope at Gan at a distance of approximately 150 metres from the reef edge, using SCUBA apparatus, but the high bottom surge made working conditions too dangerous for more than a brief examination. Here the depth was approximately 35-40 feet and the seaward beginnings of the surge channels were discernible. Corals, particularly massive palmate Acroporas were present on the areas corresponding to the base of the spurs and reached a height of no more than 4 feet above the general level of the bottoms of the groove areas. In the bases of the groove channels there was a continuous back and fore surge corresponding to the passage of each wave above, of approximately 15-20 feet. Coarse sand and fine gravel are kept in suspension in these areas, often rising to heights of 4-5 feet above the level of the floor of the surge channel. The backwards and forward motion of the bottom water was discernible to depths of approximately 70 feet on the seaward terrace.

At a distance of 200-250 metres from the reef edge a more thorough examination of the structure of the seaward reef slope was made. At this point the seaward terrace had a depth of 40 feet and sloped gradually seawards at about 10°. At a depth of 70 feet there is a slight increase in the steepness of the slope to 30-40°, extending to a depth of 130 feet and the bottom then appears to flatten out again. At 200-250 metres from the reef edge, there is little trace of the groove and spur system. The corals nevertheless appear to be in bands of approximately 10 feet wide, normal to the reef edge. Between the bands are areas of dead coral fragments, rounded and largely covered with calcareous algae though still mobile. Sand is present in places amongst the dead coral. The living coral is of three dominant types 1) a much branched twig like Acropora similar to that growing on the lagoon reef slope at Gan, 2) Echinopora and 3) a massive palmate Acropora whose growing points all pointed in the direction of the reef edge. Occasional small colonies of Pocillopora were present but there were few encrusting corals. This was in marked contrast to that seen at equivalent depths on the lagoon reef where encrusting corals were common. The calcareous alga Halimeda was to be found, particularly amongst the first mentioned type of Acropora.

At 60 feet coral growth gave way to a zone of Alcyonarians often forming masses of up to 4 x 5 feet in area. There was no sign of any banding of corals and the few small coral colonies present were randomly dispersed amongst the Alcyonarians, with areas of sand and small coral fragments between. There was no evidence here of any cementing action by calcareous algae. At a depth of 120-130 feet the bottom flattens out and is comprised largely of gravel and sand.

(ii) Seaward reef edge

Seaward reef edge features at Gan are comparable to those described in the Marshall Islands (Ladd and others 1950). The outermost zone, between the reef flat and the breakers, is formed by a platform of encrusting and nodular red and purple calcareous algae, forming a rough and irregular surface. Unlike some areas in the Marshall Islands, where the algal zone forms a high ridge, at Gan it is less distinctive topographically, forming a zone 30-50 metres wide, rising 0.5-1 ft above the level of the reef flat immediately to landward, and drying at extreme low water but not at other low tide stages. Between islands, where the level of the reef flat is lower, the relative height of the algal platform is correspondingly greater. At low tide stages, waves break outside the algal platform, where its crest begins to curve down towards the reef slope, and each breaker sends a sheet of water over the platform, the higher parts of which remain emerged. At higher tides the platform may be covered with 3-4 ft of water, and breaking of waves takes place over a wider area on the platform itself.

In places the seaward slope lineations extend through the breaker zone into the algal platform. At Gan, long sectors of the reef edge lack algal-platform channels, and often poorly and irregularly developed channels can only be seen where the platform descends beneath the breakers at low tide. At certain points, however, as at 093150 and particularly 115161, the channels cut back into the platform for 25-35 metres, forming deep, steep-sided gullies, with vertical or overhanging sides and floors 6 ft or more below the level of the intervening ridges. The channels are narrow, often less than 2 metres wide, and the ridges are wider. The sides of the channels and the intervening areas are covered with encrusting nodular and papillose brownish-red algae and other non-calcareous colonial organisms. Small colonies of Acropora are found on the channel walls and are exposed at low tide during backwash, when water level in the channels may vary vertically 3-5 ft with each wave advance. During backwash the channels act as drainage lines for water on the reef flat, which cascades over the channel lips and attached small corals; during swash, water surges up the channels and spills over the brim onto the flat, where it joins with the slower water flow over the platform surface to form a translating wave 1-2 ft deep. No signs of channel roofing or tunnel formation were seen, and no observations were made on the channels during higher tidal stages.

The Gan reef edge may be compared with that in the Northern Marshalls described by Emery, Tracey and Ladd (1954, 24-26), except that reef blocks lodged by extreme storm action are not found. At Gan the reef edge falls into the Northern Marshalls Class I, strongly grooved, Sub-type A, ridge low and uncut by grooves. In this type the algal zone is described as forming "a broad arch, sloping gently seaward and rising only 6 inches to 1 foot above the main reef flat. With rare exceptions, the grooves, though well developed, are limited to the seaward slope beyond low-tide level" (Emery, Tracey and Ladd (1954, 25). Their Type I-B, with an algal ridge 2-3½ feet above the reef flat and deeply cut by surge channels, is apparently absent at Addu. The northern reefs at Addu, not investigated in detail, appear to belong to their Class II, grooves weak or absent, Sub-type A, reef edge straight or smoothly scalloped.

(iii) Seaward reef flat

Precise levelling was carried out on the seaward reef flat, from Fedu to Gan Channel, a distance of 5 kms. Landward of the algal platform is a deeper area, or moat, 20-70 metres wide, and generally 9-12 inches lower than the highest part of the algal platform. It lacks encrusting red algae of the reef-edge type, is floored with rubble coated with filamentous algae and occasional massive Halimeda, with occasional flattened coral colonies. This moat carries a few inches of water even at lowest low tides. Landward it is succeeded by a rubble zone of small boulders, usually less than 1 ft in diameter but exceptionally up to 3 ft, and smaller rubble. This zone is as high as the reef edge platform and is exposed at lowest low water. Gravel and cobbles form irregular tongues extending lagoonward from the rubble zone across the reef flat, with maximum lengths off the southeast shore of Gan of 250 metres. Generally these debris tongues are about 50 metres long and only a few inches thick, fingering out lagoonward; there is some indication in vegetation patterns on the flat of the existence of tongues of several ages, suggesting that they may be mainly formed periodically during storms.

The reef flat itself (Fig. 9) is a rock platform thinly veneered with sand and some coarser debris, partly in transport and partly held by vegetation. The width of the reef flat varies widely round the atoll, and the width of the seaward flat depends largely on the relative location of islands on it. At Gan the total width of the reef flat is 1500-2000 metres, and of the seaward flat 600-750 metres. Most of the islands are situated closer to the seaward reef, and between Hitaddu and Hankada and Mahera and Mulikadu the seaward flat is 50-300 metres wide; the mean width of the whole reef flat round the atoll is approximately 1000 metres (cf. Section E below). The flat also varies in height. Off the central part of Gan (115-120 easting), where the flat is 750 metres wide, it stands at a relatively high level, is thickly covered with marine grasses, and dries completely from the shore to the algal platform at lowest low tides. Between Gan and Fedu, by contrast, the flat is at a lower level, carries 1-3 ft of water even at lowest tides, lacks a vegetation mat, and is covered with sand in transport. These reef flats on the southern side of the atoll differ considerably from those on the north side, and may be distinguished as windward reef flat types. They differ from many described elsewhere in the Pacific and the Caribbean chiefly in the lack of coral growth on the seaward flat itself (cf. Emery and others 1954, 27; Wells 1954, 396-398). This apparently results from the high level of the flat and its regular drying. Where the level is lower on the Gan flat, growing corals are found. This occurs in three main areas: (a) the Gan-Fedu channel, (b) the lobe-shaped inlet of deeper water at the reef edge at 106158, and

(c) on the flat near the Gan channel (130153). A few very small and scattered corals are also found in the moat and in deeper parts of the algal platform round the reef edge. These consist mainly of corymbose *Acropora* and small nodular *Porites*, tightly cemented to the flat, together with small patches of *Heliopora*. In the three deeper areas, carrying at least 1 foot of water at lowest tides, the dominant corals are widely scattered colonies of *Heliopora* and *Porites*, the latter forming "micro-atolls" the top surface of which often supports a growing mass of *Turbinaria*. In the Gan-Fedu channel, where coral growth is scattered in spite of adequate water depth, coral growth is probably restricted by the amount of sediment in transport across the flat into the lagoon: in the case of many *Porites* colonies this is indicated by scouring on the upstream face and construction of a sand tail on the lee side, which creeps up the face of the colony killing the polyps which it buries.

At Hitaddu where the seaward flat is narrower and thus more characteristic, the seaward edge is also formed by an algal platform, but the seaward flat itself is rocky, 100-200 metres wide, and 18-24 inches deeper than at Gan (precise comparison is difficult in the absence of a common datum). No part of the seaward flat dries at any time. From the algal platform to within a few metres of the shore the flat is covered with coral rubble and blocks, with scattered small colonies of *Heliopora*, *Porites* and *Acropora*. *Heliopora* nowhere reaches the importance described at Funafuti and Onotoa Atolls (Cloud 1952), but it is certainly one of the more successful colonisers on shallow seaward flats at Addu.

(iv) Northern reefs - Midu side

The northern reef flat at Addu is quite different from those described above. It is likely that it carries 1-2 feet of water over almost its whole extent at lowest tides, and circulation of water is not inhibited by the presence of islands. Considerable coral growth is found both along the seaward edge of the flat, and on the lagoon side, and the sand-floored area between is patterned by growing corals. Similar conditions are found on the flats at the northwest and northeast corners of the atoll lagoon. The patterns of coral growth on these flats resemble at a small scale those described by Kornicker and Boyd (1962, 643) at Arrecife Alacran, Gulf of Mexico. This reef flat type may be termed the leeward type.

Lagoon reefs (approximate grid ref. 045130)

The northern reefs are considerably narrower than those at the south end of the atoll and differ in morphology and species composition of the corals. The lagoon reef slope is less steep and has an estimated angle of approximately 40°, merging with the lagoon floor at a depth of approximately 80 feet. The cessation of coral growth is not so distinct and patches of coral growth are found to depths of 100 feet on the gradual slope of the lagoon floor. Chute formations were not observed. The reef edge does not form a distinct zone and the outermost area of the reef top merges with the upper area of the lagoon slope, being dominated by palmate Acroporas, although some Pavia, Galaxea and Porites are also present.

The reef flat or reef top is characterized by the very low growths of coral which rise no more than 1-1.5 feet above the level of the surrounding sand. The area between corals is typically composed of a coarse sand rather than of coral fragments. The area occupied by living coral decreases towards the centre of the reef top and in some areas 90% of the surface of the reef is covered by the sand. Corals of the genus Acropora are dominant and comprise an estimated 95% of the total coral population. There are probably five or six species of this genus present, all tending towards a rather heavy, massive growth form. Other corals observed included Millepora, Pocillopora but Echinopora and Goniastrea did not appear to be present and massive cerioid and meandroid corals were not found.

Seaward reefs (approximate grid ref. 037133)

The centre of the reef top was not observed directly but aerial photographs indicate that there is little or no coral growth and that this area is carpeted with a layer of sand. Towards the reef edge, coral growth increases in abundance. Acropora spp. are again the dominant corals, particularly A. palifera and a branching species resembling A. formosa. Altogether there appears to be about six or seven species of Acropora composing this community but occasional colonies of Millepora and Pocillopora eydouxi are also present. The only common alga is a species of Halimeda. There are very few massive or cerioid corals. The area between corals is again filled by sand which here shows evidence of sorting and is typically of large flake-like form, from 1 to several millimeters in diameter and probably derived from the breakdown of Halimeda. Towards the edge of the reef the corals form a very close community with very little non-living areas between the colonies. Where these are present they are filled by small Acropora fragments cemented together with encrusting calcareous algae. The dominant corals here are A. palifera and a massive bracket type of Acropora. These corals are actively growing and probably do not break surface at low water spring tide.

The reef edge is not distinct, but at a depth of approximately 10 feet the zone of luxuriant growth gives way to a barren zone which is characterized by the lack of vigorous coral growth. Here, instead is an area of broken coral fragments cemented into a stable structure by the growth of encrusting red calcareous algae. Very small colonies of Acropora and Pocillopora of 6-9 inches diameter make up 10-15% of the bottom cover. This zone slopes gradually seawards to a depth of approximately 20 feet and then gives way to a steeper sloping zone (slope approximately 30°) of very luxuriant coral growth. Acropora species are again dominant but Favia spp., Seriatopora, Millepora and occasional fungiids are also found. Occasional massive upgrowths, rising up to 20 feet above the general surface of coral growth were observed and these provided ecological niches for the establishment of several encrusting and nodular form corals which were not otherwise in evidence.

At a depth of approximately 80 feet a break occurs in the slope, forming a fairly distinct edge and from here the reef falls away at a slope of about 50-60° to the depths of the Equatorial Channel. Beginning at depths of 40 feet in the zone above, the area between corals is filled by a coarse sand similar to that on the seaward region of the reef flat above. The relative area occupied by the sand increases with increasing depth as the number of corals and coral species decreases. At a depth of 150 feet there are very few corals still present but small Porites colonies are of sporadic occurrence. The hermatypic corals are gradually replaced by large branching colonies of Dendrophyllia and by large gorgonian sea fans and sea whips. Algae are still present at depths of 150 feet, attached to the larger coral fragments.

The northern reefs were visited at a time of year when the predominant wind is from the southeast so that the seaward reefs were therefore in the lee of the atoll. At midday, depths in excess of 150 feet were visible from the surface and water clarity was greater than that experienced in any part of the lagoon or on the seaward reef at Gan. Morphologically the seaward reef of the northern reef system differs from that of the southern reef in:

a) the absence of a distinct reef edge breaking surface at low tides

b) absence of a groove and spur system

c) the absence of a 10-fathom terrace although it is possible that the barren calcareous algae zone is the morphological equivalent of this

d) the presence of delicate weak-framed corals and gorgonians

e) the almost total domination of the surface reef by species of Acropora, including species which were not observed at the south of the atoll.

The windward reef flats at Addu are further distinguished by the presence of areas of relict "reefrock" standing (at Gan) up to 4 feet above the general level of the reef flat. In the Gan-Fedu channel the largest of these patches are found 300 and 400 metres respectively from the reef edge, and measure 140 x 30 and 140 x 60 metres. Smaller patches are found up to 700 metres from the reef edge near the Fedu shore. At Hitaddu similar rock platforms outcrop at the foot of the seaward beach, at a distance of 100-200 metres from the reef edge. The distribution of this rock and its origin are discussed under Section G below.

At Gan there has been considerable human interference with the condition of the seaward flat. Several of the areas of exposed reef-rock have been damaged by military vehicles and by excavation, and areas of the reef flat near the Gan shore have been used as a source of reef-rock for construction purposes, particularly in the construction of the runway, leaving a pattern of excavation hollows; the approximate extent of these is given in Figure 9.

(v) Lagoon reef flat and slope

Like the seaward flat, the lagoon reef flat varies widely in character in different parts of Addu. At Gan it is narrow (100-140 metres wide) and slopes from the shore to the lagoon reef edge. Most of the flat carries more than 1 ft of water at low tide, and except for the tips of some corals none of it dries. It is divisible into an inshore sandy zone with breaking waves, a zone of rubble and dead coral from 25-60 metres from the shore, and a zone of living reef from 60 metres to the edge and down the lagoon slope. The break of slope marking the edge of the flat has depths, between coral heads, of 10-15 ft at Gan. At Hitaddu the leeward flat is much wider (reaching 1000 metres), has a depth of 1-2 fathoms, and for most of its width is sandy, covered with marine grasses, and lacking in growing corals. The reef itself appears to be similar to that at Gan. It is possible, especially at Gan, that military activity has led to increased sediment disturbance on the lagoon reef flat, with the death of nearshore corals; certainly the extent of coral growth, while comparable to that on Caribbean reefs, falls short of Gardiner's description. Detailed transects were made on the lagoon reef at Gan, and some geological aspects of these are discussed in Section D below.

The lagoon slope at Gan has a gradient of 60° from the reef edge to a depth of 14 fathoms, and is coated with growing corals. At 14 fathoms the slope angle decreases to less than 10°, and begins to merge with the lagoon floor. Coral growth in this zone is restricted to patches of Leptoseris, together with scattered Alcyonarians.

The nature of the lagoonward reefs is subject to modification between islands, where water flowing across the reef flat carries a considerable load of debris. Thus between Gan and Fedu, Fedu and Maradu, Maradu and Hankada, and elsewhere, through-flowing currents have incised deep channels into the upper part of the lagoon reef edge and slope, concentrating flow across the reef flat into narrow streams with speeds of 2-3 knots, and resulting in the growth of sand deltas at the foot of the lagoon slope.

C. Addu Lagoon

Lagoon topography

Information on lagoon topography is derived almost entirely from Daugleish's 1923 survey, in which the density of soundings exceeds even that at Eniwetok (Table 1). Since location-finding methods were less refined in 1923, however, and since the soundings were all lead-line soundings corrected for tide and not reduced from echosoundings, the accuracy at Addu may be less than in the Marshall Islands.

Table 1. Sounding density in selected atolls

Atoll	Lagoon area[1] sq.miles	Number of soundings[1]	Soundings per sq.mile
Addu	30	18,000	600
Eniwetok	360	180,000	500
Bikini	259	38,000	146.7
Rongelap	396	14,550	36.7
Rongerik	57	1,640	28.8

1. Emery, Tracey and Ladd 1954.
2. Estimated from sample counts.

The Daugleish chart has been supplemented by ten echo-sounding profiles made with a Marconi Ferrograph Offshore 500 echosounder in 1964; these have been replotted on rectangular coordinates in Figures 12-15 and the location of the echo-sounding tracks is shown in Figure 11. The Daugleish chart has been contoured and redrawn to include land topography derived from aerial photography and included on Admiralty Chart 2067 of 1964; it is included here as Figure 10.

Addu lagoon is deepest in the east and northeast, and shoals towards the north and southwest. The 30 fathom isobath delimits a basin of irregular outline, which includes a number of isolated deeper basins and a few upstanding knolls. The lagoon reef slopes are steep (Profiles 1-4, 6-7, 9-10) and extend from the lagoon reef edge at 5-15 ft to the lagoon floor at depths of 85-100 ft, where the slope angle decreases and the slope becomes a flatter apron. Chart inspection suggests that much of the lagoon floor is fairly flat at depths of 25-29 fathoms, particularly in the south and northwest parts of the lagoon, and this is also suggested by several of the profiles. Profile 1, between Gan and Man Kanda Channel, shows a distinct level at 20-25 fathoms, with deeper central areas down to 33 fathoms below this level. Similar features are shown in Profile 9. The deepest parts of the lagoon (more than 40 fathoms) lie in the south-central sector, where nine small areas fall below this level. Most of these are narrow and aligned east-west on Daugleish's chart, in the direction of sounding, suggesting systematic variation in sounding accuracy between successive lines of soundings. Hence the absolute depths of these basins may be unreliable. The maximum charted depth is 43 fathoms (258 ft).

To determine the reality of the apparent floor flattening between 20 and 30 fathoms, Daugleish's chart at 1:18,360 was contoured, and the areas between successive contours were measured using a Stanley Precision Disc Planimeter. The areas of reef flats and islands were obtained in the same way from the published Admiralty chart at 1:25,000, in which these features are plotted from aerial photography. The results of these measurements are given in Table 2.

Table 2

Depth fathoms	Area sq. yds	Cumulative area shallower	Per cent shallower	Cumulative area deeper	Per cent deeper
Islands	13,419,197				
Reef flat, 0-1 fathom, inc.islands	65,987,766				
Reef flat, 0-1 fathom, exc.islands	52,568,569				
1 - 14	12,110,207	12,110,207	13.20	91,750,231	100.00
15 - 20	11,815,554	23,925,761	26.08	79,640,024	86.80
21 - 24	19,085,942	43,011,703	46.88	67,824,470	73.92
25 - 29	22,353,011	65,364,714	71.24	48,738,528	53.12
30 - 34	14,153,743	79,518,457	86.67	26,385,517	28.76
35 - 39	11,553,133	91,071,590	99.26	12,231,774	13.33
40 - 43	678,641	91,750,231	100.00	678,641	0.74
Total lagoon area, inc. gaps	91,750,231				
Total atoll area	157,737,997				

The data in Table 2 are plotted as a histogram in Figure 16, which shows the large area of reef flat and also the dominant lagoon floor area at 25-30 fathoms. The hypsometric curve for the whole atoll (bounded by the outer reef edge) in Figure 17 gives a graphic idea of the wide shallow reef flats, the steep lagoon floor slopes between 1 and 15 fathoms, the slope foot apron at 15-21 fathoms, the wide flatter area between 21 and 30 fathoms, and the smaller extent of deeper holes in the main lagoon floor level. A percentage hypsometric curve may be constructed for the lagoon data only, and directly compared with percentage hypsometric curves constructed for the better sounded lagoons of the Northern Marshall Islands (Fig. 18), where the curves were obtained by cutting out and weighing depth zones on contour maps. The similarity between the curves for Eniwetok, Rongelap and Bikini Atolls and Addu Atoll is striking, at depths shallower than 28 fathoms, though Addu lagoon floor reaches greater depths than those in the Marshalls. The curve for Rongerik is of different form, and a curve for Johnston Island published by Emery is not really comparable because of the absence there of an enclosed lagoon (see Emery, Tracey and Ladd 1954,55; Emery 1956).

The infilling controversy

Using Daugleish's chart it is also possible to resolve the controversy between Agassiz, Gardiner and Sewell over possible aggradation or degradation of the lagoon floor. Gardiner (1903, 317-321), comparing Moresby's 1836 chart with the soundings made by his colleague Forster Cooper, argued for "a decrease in depth of from 1 to 8 fathoms, the general reduction being 2 or 3 fathoms" on the lagoon floor proper, at the same time as the encircling reefs were growing rapidly into the lagoon. He concluded that "in the 65 years between Moresby's visit and my own there has been at the least a decrease in depth of 2 fathoms over the whole area of the lagoon proper, i.e. about 15 square miles....To suppose, therefore, for the 60 odd years since the survey, a deposit or filling in by coral growth of $2\frac{1}{4}$ inches a year over an area of 22 square miles does not seem to me to be excessive" (Gardiner 1903, 320). Lagoon infilling was the reverse of the process which Gardiner thought was general in the Maldive Islands lagoons: in the case of Addu he attributed lack of solutional deepening to the landlocked nature of the lagoon, its small size, supposed lessened rate of water circulation through the reef gaps, and high rates of coral growth. Agassiz (1903, 148) questioned whether Forster Cooper's soundings were close enough to Moresby's to allow Gardiner to draw any conclusions, and emphasized the difficulty of accurate location within the lagoon. Subsequently Sewell made several more soundings (Sewell 1936a, 64), and calculated that while the "average depth" of the lagoon, excluding shoal areas, was on Moresby's chart 24.4 fathoms and on Cooper's 21.5 fathoms, Cooper's and Sewell's soundings together made it 24.5 fathoms. He hence concluded that no change had taken place. Sewell's contoured chart bears a tolerable resemblance to Daugleish's, from which the median depth read from the hypsometric curve (including shoal patches) is found to be 25.5 fathoms. The maximum depths in the lagoon were charted by Moresby as 36 fathoms, by Cooper as 32 fathoms, and by Daugleish as 43 fathoms. Subsequently Gardiner (1931, 141)ceased to stress the supposed infilling of Addu lagoon. As Sewell observed and Daugleish demonstrated, the bottom topography of the lagoon is sufficiently complex to require precise sounding location before conclusions on depth changes can be made.

Lagoon reef patches and knolls

By comparison with other atoll groups, and with the northern Maldive atolls, there are few reef structures within the Addu lagoon. Arbitrarily defining a patch reef as a structure rising more than 10 fathoms above its base and capped with wave-breaking corals, Addu lagoon patch reefs total 3. Defining knolls as structures rising 10 fathoms or more above the floor, denoted by two or more closed contours on the bathymetric chart, but failing to reach the surface, Addu lagoon knolls total 22. The total of 25 lagoon reef structures may be compared with nearly 2300 at Eniwetok, over 900 at Bikini, and 700 at Glover's Reef, British Honduras. Daugleish's density of sounding was such that it is unlikely that any major structures were unrecorded.

The knolls and patch reefs are located and given index numbers in Figure 19. Two in the centre of the lagoon, Aruhal (13, at 137084) and Medagala (14, at 136094), have living reef caps, and are normally marked by breakers, peaking up to 6 ft in height even in calm water. Of the rest, numbers 3, 23 and 24, on the west side of the lagoon, have growing coral on their summits and reach to within 2½ fathoms of the surface; number 4, reaching 4 3/4 fathoms, also has growing coral, but Davies and Keith report much dead coral also. Whether any other knolls support growing coral is not known.

Chart inspection suggests that of the knolls which fail to reach the surface there is a dominant summit level at 15-25 fathoms. The Stanley Precision Disc Planimeter was used to measure the basal area (lowest closed contour) and summit area (highest closed contour) of all 25 knolls and patches: their depth-area distribution is shown in Figure 21. Apart from Aruhal (13) and Medagala (14) all of the patches which reach within 10 fathoms of the surface are small and steep sided: the mean ratio of basal area and summit area is 7.6 and the median 4.6. None of the other knolls rises above 12.5 fathoms; six reach to between 12.5 and 17.5 fathoms; and five to between 20 and 25 fathoms. With one exception (21) the knolls rising to 12.5-17.5 fathoms all lie in the northeast part of the lagoon (numbers 7, 9-12). Those rising to 20-25 fathoms all lie in the centre of the lagoon. The mean ratio of basal to summit area of knolls rising to 12.5-25 fathoms is 24.4 and the median 9.1; the mean ratio for Aruhal and Medagala is 14.6. Of the knolls rising above 20 fathoms some show apparent terracing at the 20-25 or 25-30 fathom levels, as in numbers 12 and 21.

Comparison may again be made with the Marshalls. At Eniwetok the greatest frequency of knoll summits is at 16-20 fathoms, with few rising to 0-8 fathoms. At Bikini the greatest frequency of summits is at 4-12 and 20-24 fathoms (Emery, Tracey and Ladd 1954, 96). The concentration of the larger Addu knolls at similar depths, and the contrast between these and the smaller, steeper surface patches, suggests that the deep knolls have not been formed by reef growth in the Holocene. The echo-sounding profiles of two different types of knoll may be compared in Figure 15 (number 24) and Figure 12 (number 20). The apparent bevelling of the lower knoll summits may possibly be correlated with the apparent lagoon floor flattening shown by the depth-area histogram, and with the reported erosional undercutting of the seaward reef wall described by Hass and Eibl-Eibesfeldt, both at 25-30 fathoms. It is possible, as shown by the distribution diagram, Figure 20, that the knolls fall into two groups, one rising to about 12.5 and the other to about 20 fathoms. If these knolls are indeed older features, then they may have lost both height and steepness during karst erosion at the time of glacial low sea levels: it would be extremely valuable to have data on the nature of the knoll surfaces, and whether coral growth occurs on them. The small size of the sea-level patches (numbers 1-4, 6, 22-24) may indicate that they are wholly Holocene reef constructions. Of the larger knolls only Aruhal and Medagala reach the surface, and it is possible that they have been the only older knolls on which Holocene reef growth was established, and that the fairly small area of surface reef growing on much larger foundations represents an amount of Holocene reef growth comparable to that of the other near-surface patches. Such interpretations must be speculative until more data are available on the knolls themselves.

Notes on the structure of "Five Fathom Shoal" (095095)

Underwater observations were made on the leeward, northwestern side of this structure (no. 4, fig. 19) to a depth of 140 feet. The surface of the knoll lies at a depth of approximately 30 feet, is flat topped and is characterised by almost complete lack of coral growth. There are occasional small colonies of Pocillopora, Porites, Galaxea and Acropora but most of the surface comprises loose, uncemented skeletons of a branched Acropora with individual pieces of up to 2 feet in length and of plate-like fragments probably derived from Echinopora. The whole is carpeted with a fine leafy alga.

Below approximately 45-50 feet on the northwest side, the dead coral is replaced by fine sand and the slope is very steep to a depth of 80 feet. The sand is very tightly packed, cannot be scooped into with the hands and superficially resembles a soft sandstone. Occasional coral colonies are found in this area, with a density which rarely exceeds one per 10 square metres. A loosely branching bracket form of Acropora is the most common of these but Favia and Porites were also observed.

Below a depth of approximately 80 feet the slope begins to level off and at a depth of 140 feet the bottom is almost flat. Between these two depths reef building corals are very infrequent although one large colony of Porites was present. Small colonies of Dendrophyllia and occasional gorgonian sea whips were observed.

D. General Reef Characteristics

The main reef work of the expedition was concentrated on two lagoon reef transects at Gan (locations: 108140, between the jetties, and 113143, east of the oil jetty). Recording and collection of corals and algae in 10 feet quadrats from the shore to the foot of the lagoon slope was carried out continuously along a steel chain laid on the sea floor. Within each quadrat an effort was made to collect a specimen of every species of corals and marine algae present, and estimates were made of total percentage cover and of relative importance of particular species. Details of these transects will be published when all the determinations are available, but certain features are of geological interest and are discussed here. Figure 21 shows relative abundance of corals across each transect in terms of total number of species per quadrat; the species themselves were separated in the field and their identity will be subject to revision. Figure 22 shows the distribution of these species roughly classified by growth form. In both transects coral growth begins at about 30 metres from the shore, though scattered small colonies may be found closer, and rapidly increases to form a rich reef association at about 70 metres from the shore. From here to the reef edge at 112 metres, the abundance of species increases (Figure 21), from about 10 species per 100 sq. ft. to about 20 species per 100 sq. ft. From the reef edge to the foot of the lagoon slope the number of species remains approximately constant (10-17 per 100 sq. ft. in Transect I, 12-29 per 100 sq. ft. in Transect II). Abundance of species itself is not necessarily of geological importance, however, for many are small and often insignificant reef builders. A rough division was therefore made into species of the genus Acropora, those of the family Fungiidae, and the cerioid corals (those with adjoining polygonal calices such as Favites). Both transects show regularity in the distribution of these admittedly rather diffuse groups. The cerioid corals are important on the reef flat, forming 25-35% of the species present, but are less so on the reef slope, particularly with increasing depth. The fungiid corals are not important on the flat, but form a minor constituent on the slope. The *Acropora* spp. form one of the most important and cosmopolitan groups, generally accounting for 25-50% of the species present on the flat, and continuing to the base of the reef slope.

A rough classification of species was also made into growth form (Fig. 22), distinguishing foliaceous corals (e.g. *Pachyseris* and *Echinopora*), meandroid corals, branching corals (e.g. *Acropora*, *Pocillopora*, *Euphyllia*, and the superficially meandroid *Lobophyllia*), and the non-meandroid massive corals, many of cerioid form (e.g. *Astreopora*, *Favites*, *Hydnophora*, *Porites*, and many others). The contribution of the massive corals appears exaggerated, for many of the species represented form only small colonies. Attention may be drawn (a) to the importance of branching corals over the whole transect, and (b) to the importance of foliaceous corals on the outermost flat and particularly on the reef slope. Estimates of cover of different corals give a similar picture, particularly reinforcing the importance of reef flat Acroporas: on the outer part of the flat many quadrats show 50% of the area of living coral to be *Acropora*, and one shows 85%.

By comparison with Caribbean reefs there are certain major differences, with geological implications, in these reef assemblages. These may be summarized as:

(a) the virtual absence in the Maldives of the massive meandroid frame-building corals, such as the *Diploria* spp., and the greatly reduced significance of other massive frame-builders corresponding to the Caribbean *Montastrea* and *Siderastrea* species.

(b) the greater diversity in species and the greater area covered by *Acropora*. Branching and plate-like *Acropora* spp. are the most important corals on the Addu lagoon reefs, and most of the species present are of light and open growth form, rather than heavy and massive. On lagoon patch reef 24 the diversity and luxuriance of the *Acropora*, especially the flat, plate-like species, is remarkable, compared to the abundance of other species and to the Atlantic *Acropora*. Massive *Acropora*, comparable to the Atlantic *A. palmata*, are less common.

(c) the importance of foliaceous corals, particularly *Echinopora* on the slope, and of other open-branched, weak-framed, and often unattached corals (such as *Fungia*, *Herpolitha* and *Halomitra*) in similar situations.

It is probably reasonable to conclude from this that the Maldivian lagoon reefs are formed of much faster growing species than the Caribbean reefs, but that the reef framework formed is less rigid and more unstable than that in the Caribbean. There is, as a result, evidence of reef instability at Gan. The lagoon slope is exceptionally steep, and must approach the limits of cohesion of weak-structured corals. On the Gan lagoon slope coral growth is frequently interrupted by dead areas of broken coral and rubble, often extending from the top of the slope to the bottom, which are clearly slide scars. At times small scale sliding was seen taking place down the slope, raising turbid clouds of finer material. The reef structure, as Hass (1962) observed, is certainly a fragile and delicate one, at least near the surface, but the conclusions which Hass drew from this on the question of atoll origins misconceive the space and time scales involved. It is also possible that some at least of the larger slides have been triggered by military activities at the Gan Staging Post. Nevertheless, the evidence indicates major differences in the nature of reef growth between the Maldives and the Caribbean, and the implications of this might well be explored further.

E. Islands

Types of islands

Twenty per cent of the reef flat area at Addu is covered by islands, and the proportion would be higher if it were not for the almost island-less northern reef. The three largest islands are Hitaddu, Gan and Midu: six other islands have areas in excess of 100,000 sq. yds. The planimetric area of the islands is given in the following table:

Table 3. Areas of Addu Islands

Island	Area, sq. miles
Hitaddu	1.3943
Gan	0.8711
Midu	0.7913
Maradu	0.3118
Heratera	0.2965
Wilingili	0.1989
Fedu	0.1588
Abuhera	0.1399
Mahira	0.0464
15 small islands	0.1132
Total	4.3222

Many of the islands have only been sketchily studied, but fairly full accounts exist for Midu, Hitaddu, and particularly Heratera (Putali), and Gan and Hitaddu were visited during the 1964 expedition. The characteristics of the islands vary with size and with position on the reef flat. There are two extreme cases of island types: those formed close to the seaward reef edge, and those formed close to the lagoon reef edge (Fig. 8).

(a) Seaward-edge islands.

The seaward beach of these islands characteristically lies 45-180 metres from the algal platform, and may adjoin the rubble zone. The seaward beach is steep and high, and generally built of coral debris coarser than gravel, though in more protected areas it may be largely or wholly sand. According to Gardiner (1903, 146) raised reef-rock outcrops on the seaward beach, underlying beach sediments, wherever the shore lies within 230 metres of the reef edge, though this is by no means a general rule (Section G below). At Wilingili the seaward beach lies only 90 metres from the reef edge, is built of shingle, and was reported by Agassiz (1903, 146) to be "the highest in the Maldives". At Hitaddu the seaward beach is sandy with patches of shingle at a distance of 180 metres from the reef edge, and rises 10-12 ft above the flat; but at Abuhera, 45 metres from the edge, the beach is built of shingle and is steeper. The lagoonward beach on these islands may be 450-1000 metres from the lagoon reef edge, and is usually low and sandy, with vegetation reaching close to high tide level.

(b) Lagoon-edge islands.

In this class the island lies close to the lagoon reef edge, and correspondingly farther from the seaward reef. The distance between the lagoon reef edge and the lagoon beach ranges from 45-180 metres, and between the seaward reef edge and seaward beach from 180-1000 metres. Beaches facing the wide and often high-standing seaward reef flat are thus relatively more protected than those facing the narrow lagoon reef flat. At Gan, which falls in this class, the seaward beach is flat and narrow, and the lagoon beach high, steep and wide. Gravel and coarser debris is rare on both seaward and lagoon beaches, which are mostly sandy.

The characteristics of the larger islands thus depend to a considerable extent on relative location on the reef flat, and this varies in a fairly systematic fashion round the atoll rim. Smaller islands such as Bushy and Mulikadu are simple ridges of coral shingle and sand lodged on the reef flat by waves, and they do not show the more complex features of the larger islands. The following table classifies the Addu islands into three types: A, seaward-edge islands, B, lagoon-edge islands, and C, intermediate islands, and gives distances measured from air photographs between the seaward and lagoon reef edges and beaches.

Table 4

Island	total width of reef flat, metres	width seaward flat, metres	width lagoon flat, metres	Island type
Hitaddu	900-1350	90-180	900 +	A
Abuhera	820	45	640-900	A
Maradu	1040	600-690	180-320	C
Fedu	1130-1350	600-1350	160-180	B
Gan	1350-1800	550-690	70-90	B
Wilingili	730	90	460-550	A
Midu	300-400	90-180	-	A
Heratera	820-1260	70-90	550-900	A
Firhidu Hera	900-1000	90	730-820	A
Kalu Hera	1130	90	1000	A
Mulikadu	450	135-275	90-180	C

Island beaches

151 beach profiles were surveyed at Gan Island and 30 at Hitaddu, using a tripod quickset level and staff. Profiles were carried from the beach crest (or where vegetated the outer edge of the vegetation hedge) to a point 15-30 metres seaward of the foot of the beach. The foot of the beach is defined on most profiles by a sharp concave break of slope where the beach face meets the horizontal reef flat. In the field it is delimited by a more or less abrupt transition between white beach sands and the rocky, vegetated flat. Beach profiles may be slightly convex or concave, but most are straight with a summit convexity, except where erosion has led to scarp formation at the beach crest. A distinction may be made between (a) rough water beaches, where the foot of the beach forms a step up to 1 ft in height immediately below low tide level, often with an area of strongly rippled sand to seaward, and (b) calmer water beaches, where this step is absent. Beach profiles were measured over a period of weeks, but always at similar tidal stages, i.e. during the 4-5 days of exceptionally low low tides occurring at fortnightly intervals. Gan profiles 1-5 were also repeated at a medium high tide (profiles 6-10).

Considerable differences were found in beach angle in areas with different exposure to wave activity. At Gan the profiles were grouped into beach sectors (Fig. 23), separated by areas unsurveyed because of human interference or other reasons. Within each sector, beach angles tend to be tightly clustered about a mean value (except on the east shore, where values are more widely scattered), but there are considerable differences between beach sectors. Mean beach angles for Gan beach sectors are as follows:

Table 5

Beach sector	Number of profiles	Mean angle
East shore	10	5.75°
North shore (east)	10	7.95
North shore (centre)	56	8.30
North shore (west)	15	8.07
West shore	14	4.18
Southwest shore	36	5.77
Total and Mean	151	7.01

These beach angles correlate directly with exposure. Wave activity is most intense on the lagoon shore between the two jetties; it is high along the whole lagoon shore, and much less on the east and west shores where the reef flat is wider and shallower. On the southwest shore the beach is rather more exposed to waves in the wide and deeper Gan-Fedu channel, and beach angles are correspondingly higher. The steepest beach angle recorded at Gan is 11.5° in profile 58. The south shore of Gan, facing the exceptionally wide seaward flat, is most protected from wave action: the beaches are low and flat, and vegetated almost to high tide level; this, together with the fact that this shore has been used since World War II as a rubbish dump for military debris, made profiling impossible.

At Hitaddu similar contrasts are found in beach angles, again corelating with wave energy, but whereas at Gan the steepest beaches are on the northern lagoon shore, at Hitaddu they face the narrow seaward reef flat, and the more protected lagoon beaches are lower and flatter.

Table 6

Beach sector	Number of profiles	Mean angle
Seaward shore	19	9.5°
Lagoon shore	11	5.2

The steepest beach angle measured at Hitaddu was 13° on seaward shore profile B9.

Inspection of the Gan profiles shows that the width of the beach tends to be fairly constant between the sectors measured (not including the south shore): width averages 14-16 metres, and varies extremely from 7 to 23 metres. The height of the beach above the immediate offshore flat (i.e. above the concave break of slope at the beach foot) is more variable, and is directly related to beach angle. On beaches with a mean angle of 5° or less, the height of the beach is 5 ft or less. On steeper beaches (angle greater than 8°) beach heights are greater than 5 ft and range up to 10.5 ft. Steep, high beaches are built in exposed areas where rapid swash builds the beach face above still high-water level. The most sheltered beaches have heights approximately equal to the tidal range. Median beach heights for different beach angles at Gan are as follows:

Table 7

Beach angle, deg.	3	4	5	6	7	8	9	10
Median height, ft.	3	4	5	4	5	6	7	8

Similarly at Hitaddu, the width of the seaward beach averages 15 metres, varying from 13 to 20 metres, and that of the lagoon beaches averages 13-14 metres, varying from 10-15 metres. Main variability is in beach height, which again directly correlates with angle:

Table 8

Beach angle, deg.	5	5.5	8	9	10	11	13
Median height, ft.	4	4	7*	7	7	8*	10*

(* single cases only)

Plotting median height and height range against beach angle in Figure 24 indicates the range and variability of these beach characteristics; the regression line is fitted by eye.

Interior topography

Most of the Addu islands consist of seaward and lagoonward ridges, separated by a lower area, in places occupied by water. The eastern islands consist of a rocky seaward ridge and sandy lagoon ridge, separated by freshwater lakes or kuli (Willis and Gardiner 1901, 78). Air photographs show a large interior lagoon at Hitaddu, but this could not be visited. Much of the central part of southern Hitaddu was covered with standing water 6-24 inches deep in August 1964, under a vegetation of sedges and Pandanus thicket. At Gan the interior topography has been considerably altered by construction work, but in the centre of the island the soil is black and mucky, with the water table at or within an inch or two of the surface. Excavation at several places showed a clear distinction between soils derived from peripheral sand ridge sediments, and those formed under high water table conditions in the centre of the island. Unlike many Pacific and Caribbean islands, mantles of coarse sediments ("rampart wash") in the interiors of islands, resulting from exceptional storm activity, seem to be absent at Addu.

The height of the water table is such that after heavy rain fresh water may stand on the island surfaces for several days, and in places permanently. This is the case at Gan, where levelling of the surface has added to drainage difficulties, but also at Hitaddu. Gardiner described similar conditions at Maradu (Willis and Gardiner 1901, 80). Rainwater replenishment of the Gan freshwater lens is sufficient to supply all freshwater requirements for the R.A.F. Staging Post established there.

Minor changes in Addu island topography

The records of 1836, 1900, 1934 and 1964 show that some features of the Addu islands are subject to minor alteration, particularly where gaps between islands are narrow and shallow. Islands charted as separate by Moresby and even by Gardiner may now be joined; and some small islands may have disappeared. Sewell has chronicled the changing numbers of small islands off northwest Midu: 6 in 1836, 7 in 1900, 5 in 1934 (Sewell 1936a, 73-74); in 1964 there were three, two small, and one (Mahira) long and narrow. Heratera and Firhidu Hera were separate in 1836, joined in 1900 (Gardiner 1903, 318), separate in 1934 (Sewell 1936, 74), and joined in 1964. Wilingili, charted as two islands in 1836, had become one by 1900 (Gardiner 1903, 418), and remains so. In 1836 Abuhera was continuous with Hitaddu, and remained so in 1900 (Gardiner 1903, 415). By 1934 the two were separated (Sewell 1936a, 84), but were again joined in 1964, by a sandy area with continuous vegetation cover, standing 3.5-4 ft above the level of the reef flat immediately to seaward, with a seaward sand and shingle ridge 2.5 ft higher (Profile B19). The series of small islands on the seaward side of Fedu and Maradu, uncharted in 1836 but recorded by Gardiner, were probably omitted in error by Moresby; they are discussed by Gardiner (1903, 419) and Sewell (1936a, 80-81). The scrub vegetation described by Sewell has now been replaced by coconut thicket with trees 45-50 ft tall.

According to Agassiz (1903, 147-8) and Kohn (1964b) the lagoon and southwest shores of Gan are being eroded, while Sewell (1936a, 80) inferred aggradation. Evidence for beach retreat is given by the beachrock at the northwest point, which is now being actively undercut by throughflowing water in the Gan-Fedu channel; by the exposure of cay sandstone on the beach face on the southwest, west, and to a lesser extent the northern shore; and occasional undermining of trees at the eastern end of the north shore. Retaining walls have been built to stabilise the shore on parts of the west and north shores. For details of the beachrock and cay sandstone exposures, see Section G(iii) and (iv). Local aggradation is taking place at the northeast point of Gan, where a fresh sand spit extends 60 metres from the main beach crest.

F. Sedimentary environments

The main aim of the geomorphic work was the sampling of sediments in a variety of atoll environments, to demonstrate (a) how sediment characteristics varied between environments within the depositional framework of the atoll, and (b) how sediment characteristics (mechanical and organic composition) vary on the beach face and the immediate nearshore area in a number of beach sectors subject to differing wave intensities at Gan and Hitaddu Islands. The main sedimentary environments sampled were (1) island beaches, (2) reef flat, (3) lagoon reef slope, and (4) lagoon floor. On beaches sampling was carried out at the same time as beach profiling, on a total of 250 beach profiles. Samples were collected at 5 metre intervals on each profile, measured from the beach crest, and the profiles were generally spaced at 25 metre intervals along the beach. Generally 5-6 samples are available per profile: the profiles are located in Figure 23. The total number of beach face and immediate nearshore samples collected at Gan numbered 950, and at Hitaddu 99. Sampling of reef flat environments was carried out on the seaward flat at Gan, and in the Gan-Fedu channel, concurrently with levelling. Location of the reef flat samples, totalling 127, is shown in Figure 25. On both beaches and reef flat sampling was carried out with a simple scoop sampler holding approximately 300 grams. On the lagoon reef slope 5 samples were collected by Keith using SCUBA apparatus. On the lagoon floor sampling was carried out using a bronze grab sampler which closed automatically on striking the bottom. Recovery of samples was poor because of frequent malfunction of the release, and the total number of samples collected was 42; their location is given in Figure 26. Processing of these samples for machine computation of mechanical characteristics is continuing, and this section simply records some gross characteristics of reef flat, beach and lagoon floor sediments, on the basis of preliminary data for 350 samples. As measures of sediment characteristics, cumulative percentage curves were drawn from sieve data and used to derive phi median diameter (ϕM_d) and sigma phi ($\sigma\phi$), the latter giving a simple measure of sorting ($\phi \; [\phi 84 - \phi 16] / 2$).

Using these parameters clear distinctions may be made between reef flat, beaches and lagoon floor environments (Fig. 27). In the reef flat sediments as a whole the mean ϕM_d is about 0.5, a coarse sand, with a range from -1.3 to +1.7 ø (very fine gravel to medium sand). Taking the Gan beach sediments as a whole, mean $øM_d$ size is about 0.85, a less coarse sand, with a range from -0.2 to +2.1 ø (very coarse sand to fine sand). The lagoon floor sediments are highly variable in size composition, ranging from less than 1.0 to more than 4.0 $øM_d$ (coarse sand to coarse silt). There is therefore some distinctiveness in size range between the three environments (note that no attempt was made to sample beach sediments coarser than fine gravel, such as the shingle or rubble sediments on the seaward beach of Hitaddu). Taking median size characteristics alone, however, there is considerable overlap, particularly between reef flat and beach sediments. Sorting is more discriminatory. Although the sorting measure used here is rather inefficient and was chosen for ease in calculating, it is clear that considerable differences in sorting exist between environments. Beach sorting values are almost all less than 1.0, except where the sediment sampled is obviously bimodal; the peak frequency of beach sorting values is 0.5-0.6, i.e. beach sediments are very well sorted. By contrast, reef flat sediment sorting values range from 0.7 to 2.1, with a mean value of about 1.5, i.e. sorting is much poorer. Lagoon floor samples have similar or higher sorting values than those on the reef flat. Plotting of median size against sigma phi in Figure 28 shows that reef flat and beach sediments are clearly distinguishable in terms of size and sorting; data are too few to accurately define the range of lagoon floor characteristics. In summary:

(1) beach sediments are moderately fine sands and very well sorted;
(2) reef flat sediments are coarser and poorly sorted;
(3) lagoon floor sediments are coarse to very fine, and poorly sorted.

There is in addition considerable variation within the major environments. The beach sampling programme was designed to assess changing sediment characteristics normal to the shore, particularly in the light of Miller and Zeigler's (1958) model of beach sediment characteristics. Preliminary results indicate that sediments are coarsest at the foot of the beach, at the "step" on rough-water beaches, and become finer in median diameter both to seaward of the beach foot and up the beach face. Sorting is also best in the lower part of the beach, and decreases to seaward of the beach foot and up the beach face. Much work needs to be done on the data, however, before conclusions can be drawn. Similarly on the reef flat, a distinction can be made between flats backed by islands and channels, since considerable sediment transport and sorting occurs through the Gan-Fedu channel, by comparison with more stable conditions on the vegetated flat south of Gan.

G. Lithified sediments

Lithified sediments of various types have been described from the Maldive Islands by Moresby, Gardiner, Agassiz and Sewell, and Gardiner in particular has used the present distribution and height of lithified sediments on the atolls as evidence for considerable shifts of sea level in Recent times. In many discussions of lithified sediments, genesis has been deduced only from the gross topographic characteristics of the outcrop, and it has then been assumed that similar outcrops have a similar composition. Few discussions of atoll rocks consider lithology and mineralogy as well as topography and distribution, and many of the earlier deductions on rock origin and its implications in terms of geomorphic history are purely speculative.

Gardiner (1903) and Sewell (1935a, 500-512) distinguished three main types of rock on atolls: reef rock, beach sandstone or beachrock, and cay sandstone. All these types are found at Addu Atoll, but a further distinction must be made between reef rock underlying the modern reef flat, and raised or relict presumed "reefrock" of uncertain status. This account is purely descriptive, and no attempt is made to describe the mineralogy or origin of the rocks, or their bearing on atoll history at this stage.

(i) Reef rock

Wherever investigated the reef flats of Addu atoll consist of a more or less regular rock platform, veneered with loose sediment. This is particularly so south of Gan, on the wide seaward reef flat, which is wholly a rocky feature, lacking any considerable relief, and giving no indication of subsurface structure in the form of either curvilinear fracturing or of truncated and relict coral heads described from such flats elsewhere. Samples of reef rock were obtained by blasting on the seaward reef at Gan, location 115159, through the courtesy of Mr. J. Woodward. The rock is a toughly cemented rock of coral fragments in a limestone matrix, with abundant Heliopora fragments which have lost their blue colour and turned brown. The constituents indicate a reef community similar to that now found on deeper flats than the present Gan flat. It is difficult to see how such rock could form at the present level of the flat off central Gan.

(ii) Relict "reef rock"

Several of the seaward-edge islands have low rock platforms at the foot of their seaward shores. Gardiner (1903, 416) described this as occurring wherever part of the island lies within 230 metres of the seaward reef edge; at Hera, north of Midu, he described emerged reef-flat rock masses standing up to 6 ft above high water and 10 ft above the flat. At Midu, rock is described along the east shore, reaching 5 ft above high water (Gardiner 1903, 417; Sewell 1936a, 73, Plate lii). Seaward-beach rock masses are also described at Heratera (Sewell 1936a, 75, Plate 3ii), Firhidu Hera and Kalu Hera (Sewell 1936a, 79), Mulikadu (Sewell 1936a, 79), and Maradu (Sewell 1936a, 82). Sewell also describes it between the seaward shore and the reef edge at Maradu, forming "coral horses" (Sewell 1936a, 83, Plate 3i), and in the small islands between Fedu and Maradu (Sewell 1936a, 81).

"Reef rock" of similar type is present on the seaward shore of Hitaddu, where it was surveyed in beach profiles B1, B12, B14 and B15.

In profile B1 the highest point of the reef rock outcrop, which is 4 metres wide, reaches 4.3 ft above the general level of the reef flat, but only 3 ft above the level of the flat immediately seaward of the rock. It outcrops at the foot of the beach, which here rises 6 ft above lowest low water, and the rock itself dries at least 1.5 ft at this stage. Other profiles show similar characteristics, except that the beach face above the rock is only 3-4 ft high. In places the upper surface of the rock shows a distinct seaward gradient (4.5° in B1, 3° in B12), but this is clearly erosional: elsewhere the surface is rough but horizontal. The structure of this relict rock is not easily discernible, but at places on the southernmost part of the Hitaddu seaward shore and the northernmost part of Abuhera the coral slabs forming the rock are clearly imbricated, dipping seawards, which might indicate a subtidal reef flat rather than a beach environment.

Several patches of rock, mentioned by Gardiner and Sewell, are found in the reef flat embayment between Gan and Fedu Islands, and on the wide reef flat to the south of Gan. The patches are as follows: (1) A rock platform marked on charts as Addu Island, south of Gan, location 1048/1536-1550, measuring 140 x 30 metres, the highest part rising 5.1 ft above the deepest part of the seaward flat between it and the reef edge, and 3.45 ft above the level of the reef edge algal platform. (2) A large patch 800 metres to the northwest, 220 metres from the seaward reef edge, location 0958-0966/1486-1500, rising at its highest 4.3 ft above the surrounding reef flat. (3) Two small patches of rock, the largest 35 x 23 metres, approximately the same distance from the reef edge, with a similar height, location 091143. (4) A small patch of rock standing 3 ft above the reef flat approximately 30 metres to the northwest. (5) A much larger patch, the first of a series, location 089142, which continue towards the northwest and form the basis of several of the small islands on the seaward side of Fedu, as described by Sewell. (6) Two small patches, location 095139, close to the southeast shore of Fedu, drying up to 2 ft at low water, marked on the Admiralty chart as "drying 4 ft." In all these cases the rock surface is deeply pitted and eroded, and in cases 1 and 2 it has also been damaged by military activity. The rock is formed of coral fragments in a coral sand matrix, and in places is dominantly sandy.

(iii) Cay sandstone

The Maldive Islands form a classic area for the description of cay sandstone. Moresby (1835, 398) described subsurface induration of sands at a depth of 3-4 ft, forming a layer 2 ft thick overlying unconsolidated sands, at the freshwater table, at Miladumadulu Atoll. Sewell (1935a, 502-3) described a similar occurrence at Maradu Island, Addu Atoll, and also figured a section at Fehendu Island, Goifurfehendu Atoll (cf. Sewell 1936b), where a layer of sandstone 1½ ft thick underlies 2-3 ft of surface sands and soil, well above high water level.

Cay sandstone is well exposed on the west and southwest shores of Gan, where it forms a nearly horizontal ledge or platform several feet wide on the upper part of the beach. The rock is generally 1-2 ft thick;

its base is dry at low water, but its upper surface is covered by swash at high tide. Its seaward edge forms a vertical or overhanging scarplet, which is being eroded by transverse gullying, by local undermining and wave action, and by the dislodgment of sections several metres long because of longitudinal fracturing. Inland the rock passes under the beach, and at one point outcrops in the eroded beach face to a height [illegible] inches higher than the platform, suggesting that the upper surface of the rock may itself be erosional. The rock is poorly bonded and may generally be crumbled in the fingers at fresh sections; at the outcrop it is casehardened and tougher. It lacks internal structures in bedding or grain size sorting, and is essentially horizontal.

Cay sandstone outcrops on the west shore, as recorded in beach profiles 76, 77, 78 and 79. These are all low-angle beaches (gradients 1 in 10 to 1 in 15), the beach crest rising 5 ft above the immediate offshore flat. Cay sandstone outcrops 1.3-2.5 ft below the beach crest, forming a platform 2.3-5.6 metres wide, and 1-1.5 ft thick. On the southwest shore, cay sandstone outcrops are shown in beach profiles 92, 95, 96, 98, 99 and 100. Beach gradients here range from 1 in 5 (where there has been considerable steepening as a result of erosion) to 1 in 16. The height of beach crests above the flat ranges from 5 to 9 ft. The sandstone outcrop is 1-6.4 metres wide; it passes landward beneath unconsolidated beach sands which form a vertical scarplet up to 2.5 ft high. The outer edge of the rock platform forms a scarplet 0.5-2 ft high. The height difference between the sandstone platform and the beach crest depends on the amount of human interference with the latter: at its greatest, where the erosional sand scarp is highest, the platform is 3.3-4 ft below the beach crest. Elsewhere it may be only 1-2 ft. Profile 99 shows the rock with a maximum thickness of 3.4 ft; generally it is 0.5-2 ft. The surface of the platform is often tilted slightly seawards, but at a very much smaller angle than intertidal beachrock.

No outcrops of cay sandstone were seen at Hitaddu, but Sewell describes outcrops of similar rock on the lagoon beach at Heratera (Sewell 1936a, 76, Plate 4iii).

(iv) Beachrock

Intertidal beachrock has been classically described from the Maldive Islands by Gardiner (1903, 341-346, Plate 16), and its characteristics are now well known. Gardiner insisted on its intertidal character (1903, 343), and this appears to be a useful field criterion for beachrock identification. Beachrock is uncommon on Addu beaches, where it must not be confused with outcropping beach sandstone on the upper beach face, exposed by beach retreat. Outcrops of beachrock are found in two places on the Gan beaches, the largest being at the northwest point (1014/1367). Three lines of beachrock continue the trend of the north shore towards the deeply scoured Gan Channel. The rock is eroded and discoloured by algae, the outer line blackened, the inner lines grey and brown, but by contrast with the Caribbean, larger algae such as Turbinaria are absent, doubtless because of the high tidal range. The beachrock is shown in beach profiles 72 and 73. The lowest seaward part of the beachrock stands 1.5 ft above the level of the lagoon reef flat, at this point a hard planed rock floor; the highest landward part of the beachrock stands 4 ft above the flat and 3.5 ft below the beach crest. Low tide level approximates to its lowest extent, and the rock is submerged at high tide. The three lines of beachrock all dip seawards: the innermost at 3°40', the second at 5°36', and the outermost at 6°30'. They are separated by scarps 1-1.4 ft high. At its westernmost extent the beachrock is being undermined by current scouring in the Gan channel, and several slabs have been broken transversely and have fallen into scour holes. At the end of the beachrock the channel floor lies 4 ft below the beachrock surface, and as a result of this scouring there is a secondary longitudinal tilt in the exposure.

Possible massive beachrock outcrops on the north shore of Gan, (a) immediately west of the marine jetty (1060/1394), where it has been much altered by man, and (b) in four small patches at the eastern end of the north shore (124144), where it is difficult, however, to distinguish it from possible cay sandstone on morphologic grounds. Similar difficulty is also experienced with some of the outcropping rocks figured by Sewell at Goifurfehendu Atoll (Sewell 1936b). Unmistakable beachrock was not seen at Hitaddu, though a lagoon beach exposure south of the jetty may be so classed. Gardiner also reports beachrock on the seaward beach at Midu (Gardiner 1903, 417).

The Gan beachrock consists of sedimentary particles similar to those of the adjacent beach, showing vertical sorting into distinctive layers dipping seawards, which helps to differentiate it from cay sandstone. The constituent particles show evidence of solution, and the rock has been secondarily cemented to an extremely tough and hard character.

Problems

The problems posed by the Addu lithified sediments may be briefly stated. The nature of the relict "reef rock" is of critical importance in the geomorphic history of the atoll. Gardiner and Sewell supposed it to be a true submarine reef rock exposed by relative elevation, but it is also possible that it has been formed by lithification of coarse island clastic sediments at its present elevation and exposed by beach retreat, as Newell suggests in the Tuamotus (Newell 1961). Bearing on this problem is the generally unsorted nature of the constituents and the imbrication of coral slabs at Hitaddu. Even though there is no evidence of corals being found in the rock "in the position of growth", as Gardiner observed at Minikoi and elsewhere, this seems to indicate a subtidal origin, implying a relative shift of sea level. The widespread nature of similar exposures elsewhere in the Maldives and in the Indian Ocean generally (Sewell 1935a, 474-479; 1932, 1928) would also lend support to a negative eustatic shift in explanation of these raised features. It is interesting in this connection that Shepard (1963, 5) has obtained a radiocarbon date of 2990 ± 220 yrs B.P. from a raised reef 2-3 ft above low tide level in Ceylon, although comparable Pacific and Australian features have yielded considerably older dates. At Gan the rock has been subject to considerable alteration by erosion, and is probably undatable. However, samples of reefrock underlying the present flat should give significant results: if near-surface samples are very old, they may indicate antiquity and subsequent planation of the flat, from which the higher fragments of reefrock rise as erosional remnants; but if young, it will be difficult to attribute the relict rock to any major eustatic shift of sea level.

The nature of the cement in the cay sandstone and the intertidal beachrock is of interest. If, as seems likely, the cay sandstone is a freshwater rock and the beachrock marine, the primary cements should be calcite and aragonite respectively (Stoddart and Cann 1965). In the case of the Gan beachrock, however, solution may have gone too far for the primary cement to be determined. Alternatively, if the beachrock cement is calcite, this will add further evidence to Russell's theory of beachrock origin at the freshwater table under beaches (Russell 1962). A major problem is why rock of one sort is developed on a particular island, rather than another. At Gan, cay sandstone is the dominant lithified material, whereas at Cocos-Keeling Russell and McIntire (1965) report massive beachrock.

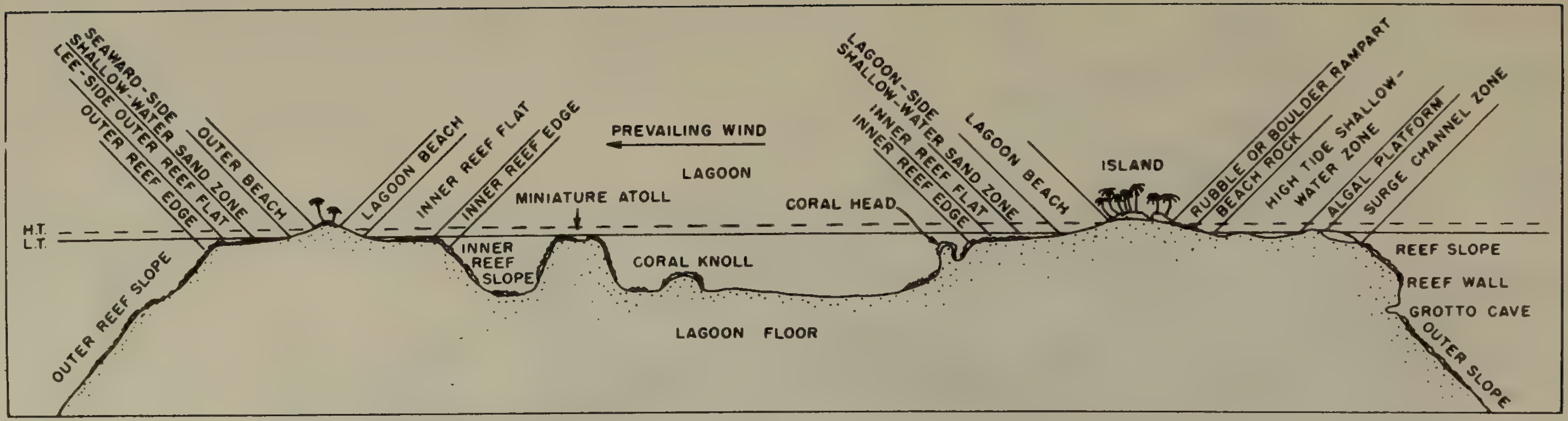

SEAWARD-SIDE SHALLOW-WATER SAND ZONE
LEE-SIDE OUTER REEF FLAT
OUTER REEF EDGE
OUTER BEACH
LAGOON BEACH
INNER REEF FLAT
INNER REEF EDGE
PREVAILING WIND
LAGOON
MINIATURE ATOLL
H.T.
L.T.
OUTER REEF SLOPE
INNER REEF SLOPE
CORAL KNOLL
LAGOON FLOOR
CORAL HEAD
LAGOON-SIDE SHALLOW-WATER SAND ZONE
INNER REEF FLAT
INNER REEF EDGE
LAGOON BEACH
ISLAND
RUBBLE OR BOULDER RAMPART
BEACH ROCK
HIGH TIDE SHALLOW-WATER ZONE
ALGAL PLATFORM
SURGE CHANNEL ZONE
REEF SLOPE
REEF WALL
GROTTO CAVE
OUTER SLOPE

Fig. 7. Zonation of Maldivian reefs, after Eibl-Eibesfeldt (1964).

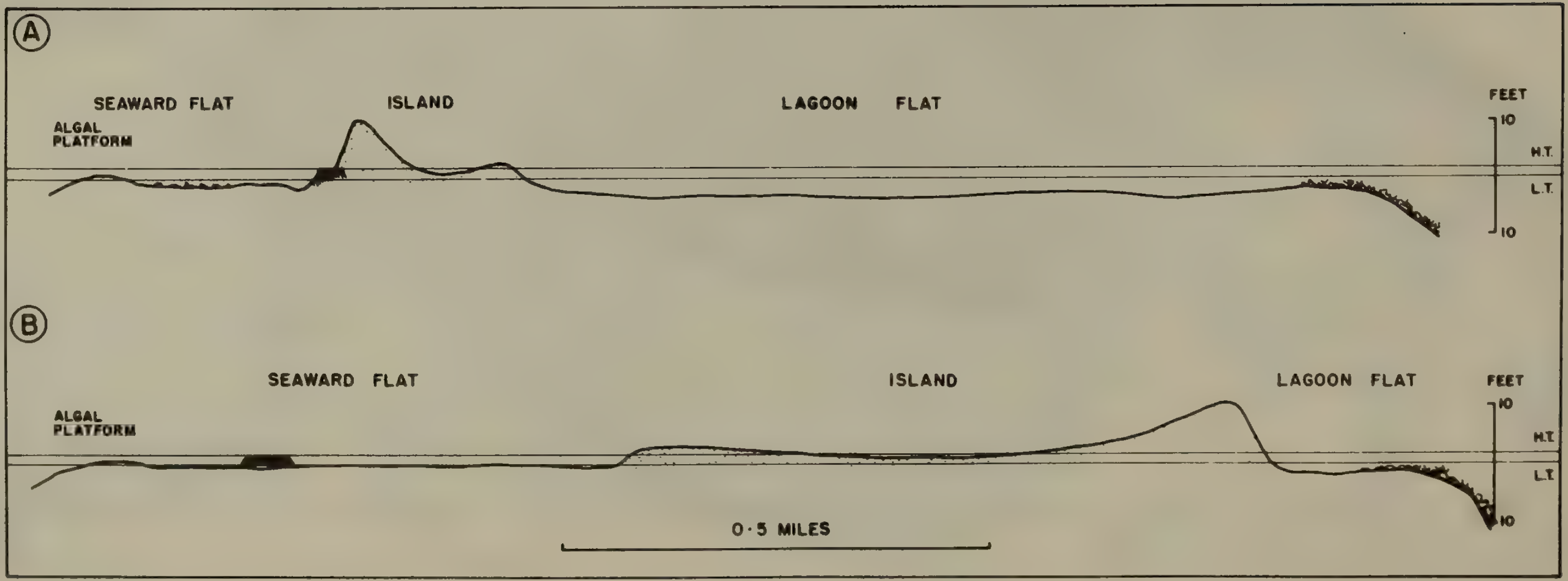
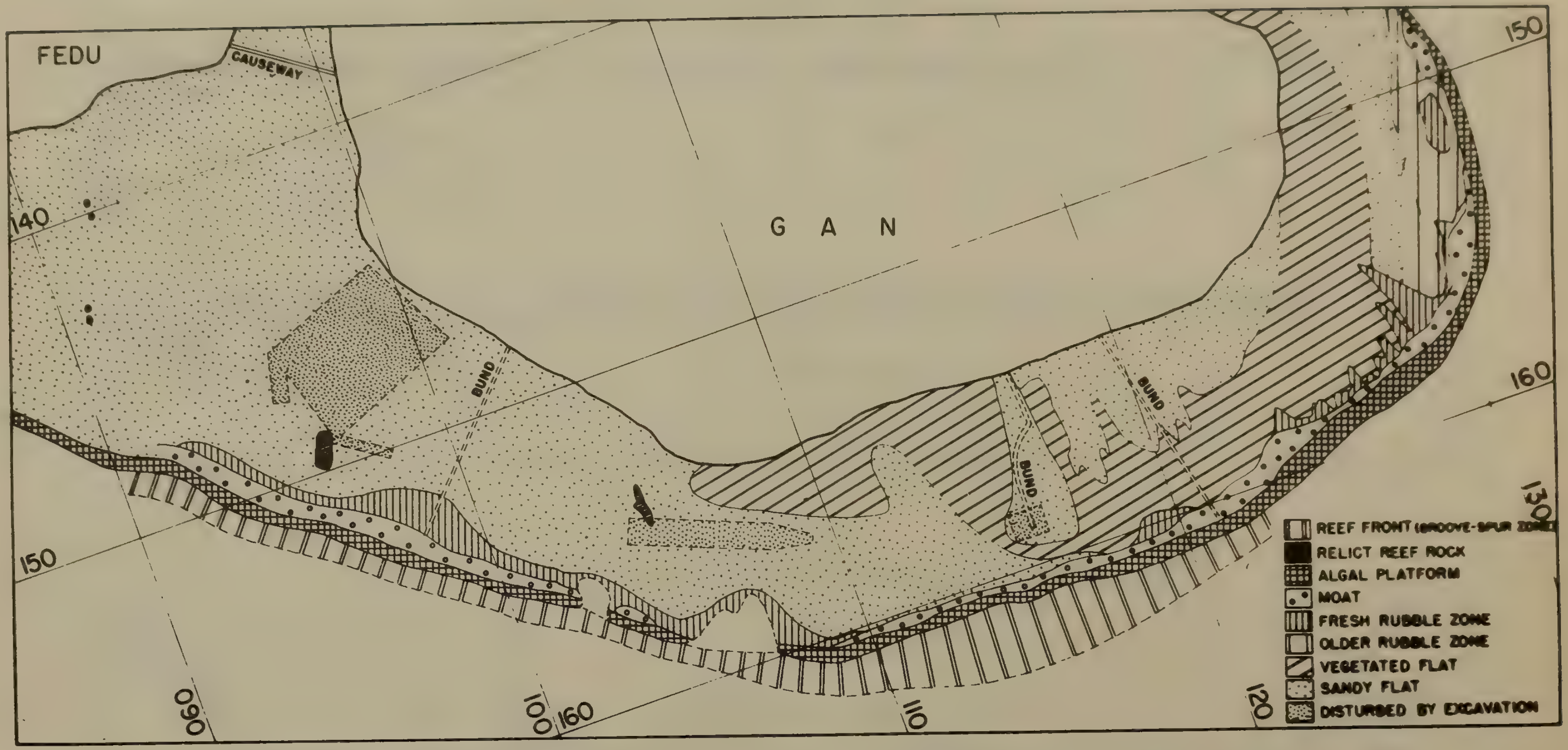

A
SEAWARD FLAT
ALGAL PLATFORM
ISLAND
LAGOON FLAT
FEET
10
H.T.
L.T.
10
B
SEAWARD FLAT
ALGAL PLATFORM
ISLAND
LAGOON FLAT
FEET
10
H.T.
L.T.
10
0·5 MILES

Fig. 8. Diagrammatic cross-section of peripheral atoll reefs at (A) Hitaddu and (B) Gan Islands, Addu Atoll.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G A N
BUND
BUND
BUND
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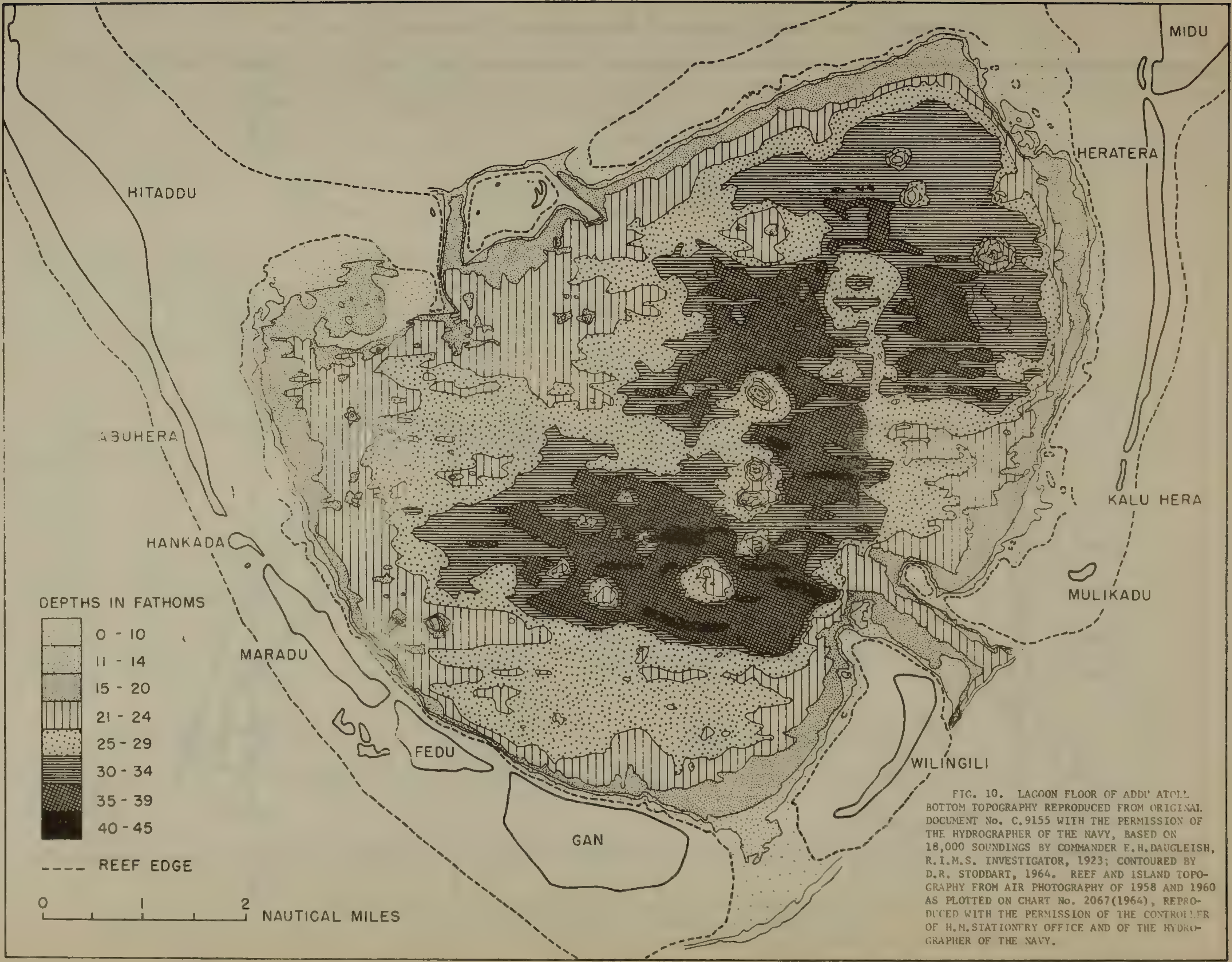
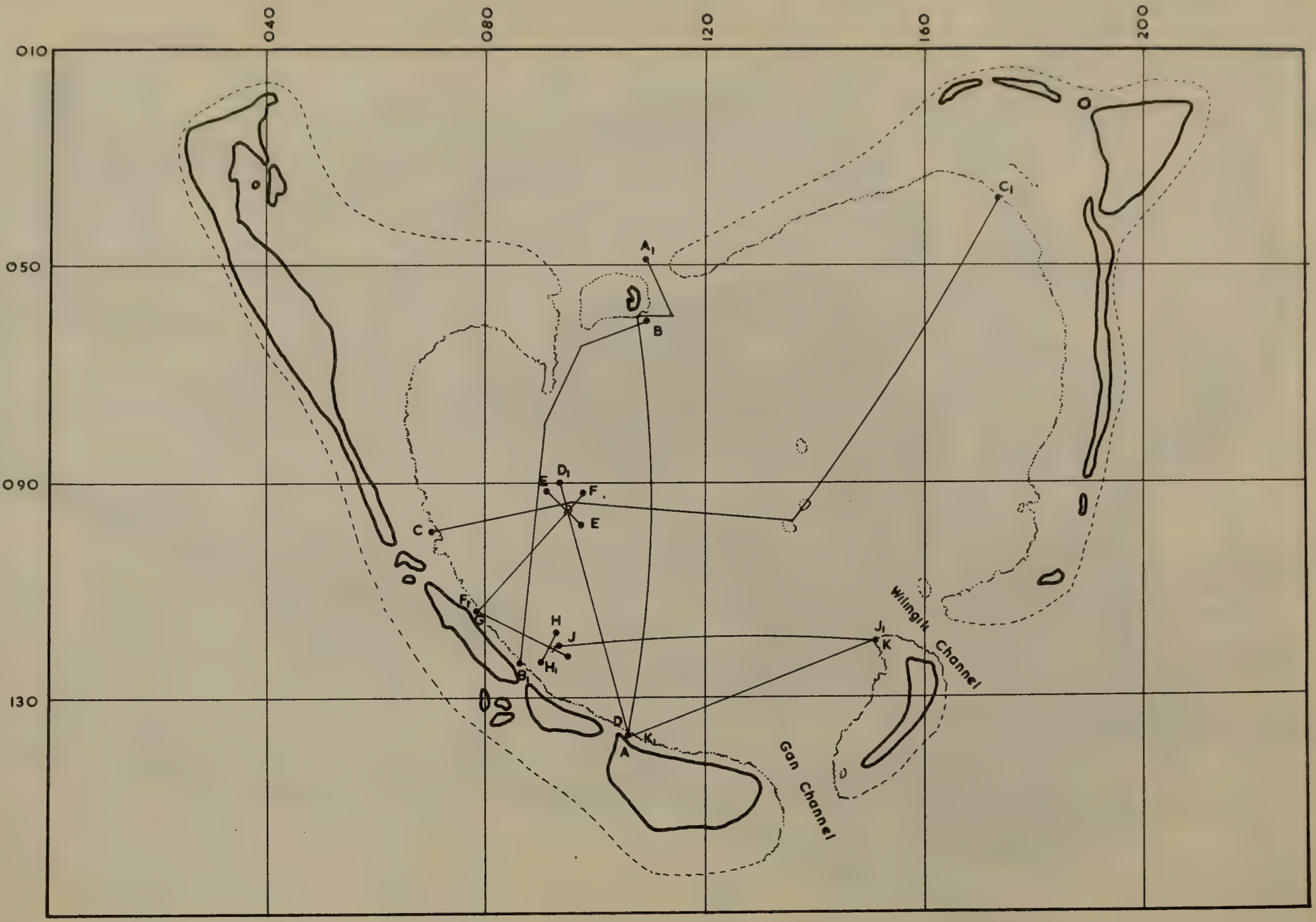
150
150
160
130
160
090
100
110
120
REEF FRONT (GROOVE-SPUR ZONE)
RELICT REEF ROCK
ALGAL PLATFORM
MOAT
FRESH RUBBLE ZONE
OLDER RUBBLE ZONE
VEGETATED FLAT
SANDY FLAT
DISTURBED BY EXCAVATION

Fig. 9. Ecological zonation on the seaward reef flat at Gan Island



MIDU
HERATERA
HITADDU
ABUHERA
KALU HERA
HANKADA
MULIKADU
MARADU
FEDU
WILINGILI
GAN
DEPTHS IN FATHOMS
0 - 10
11 - 14
15 - 20
21 - 24
25 - 29
30 - 34
35 - 39
40 - 45
REEF EDGE
0
1
2
NAUTICAL MILES

FIG. 10. LAGOON FLOOR OF ADDU ATOLL. BOTTOM TOPOGRAPHY REPRODUCED FROM ORIGINAL DOCUMENT No. C.9155 WITH THE PERMISSION OF THE HYDROGRAPHER OF THE NAVY, BASED ON 18,000 SOUNDINGS BY COMMANDER E.H.DAUGLEISH, R.I.M.S. INVESTIGATOR, 1923; CONTOURED BY D.R. STODDART, 1964. REEF AND ISLAND TOPOGRAPHY FROM AIR PHOTOGRAPHY OF 1958 AND 1960 AS PLOTTED ON CHART No. 2067(1964), REPRODUCED WITH THE PERMISSION OF THE CONTROLLER OF H.M.STATIONERY OFFICE AND OF THE HYDROGRAPHER OF THE NAVY.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C1
C
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F1
G
H
H1
J
J1
K
K1
A
B1
Wilingili Channel
Gan Channel

Fig. 11. Location of echosounding profiles in Addu Atoll lagoon.

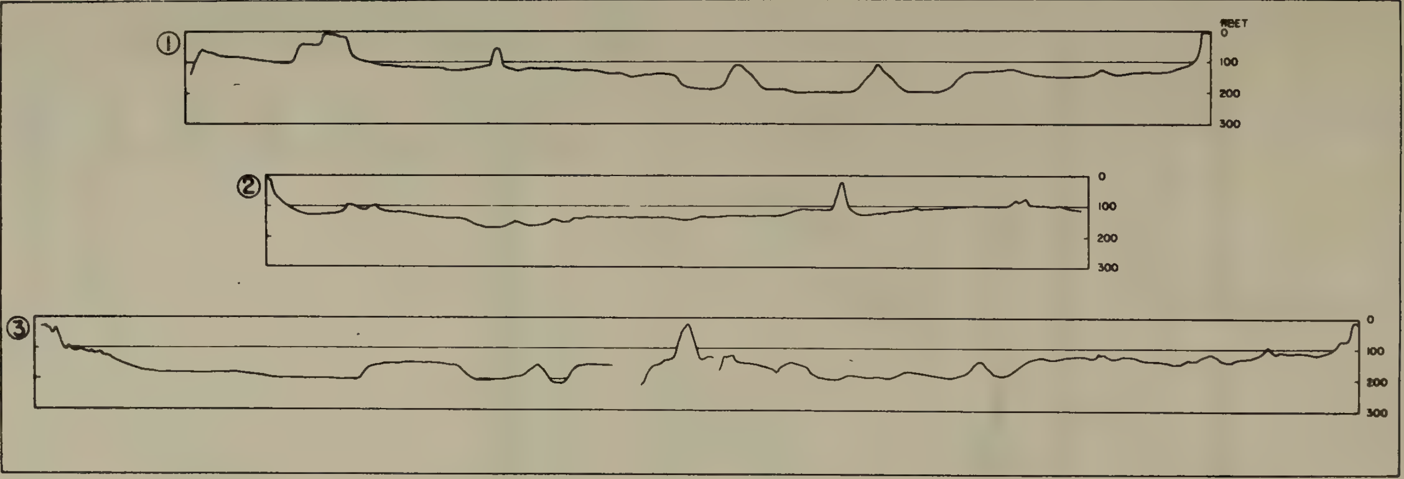


Fig. 12. Addu Atoll lagoon echosounding profiles 1-3; for location, see Figure 11, 1: A-A_1; 2, B-B_1; 3, C-C_1. Horizontal scale approximately 1:55,000

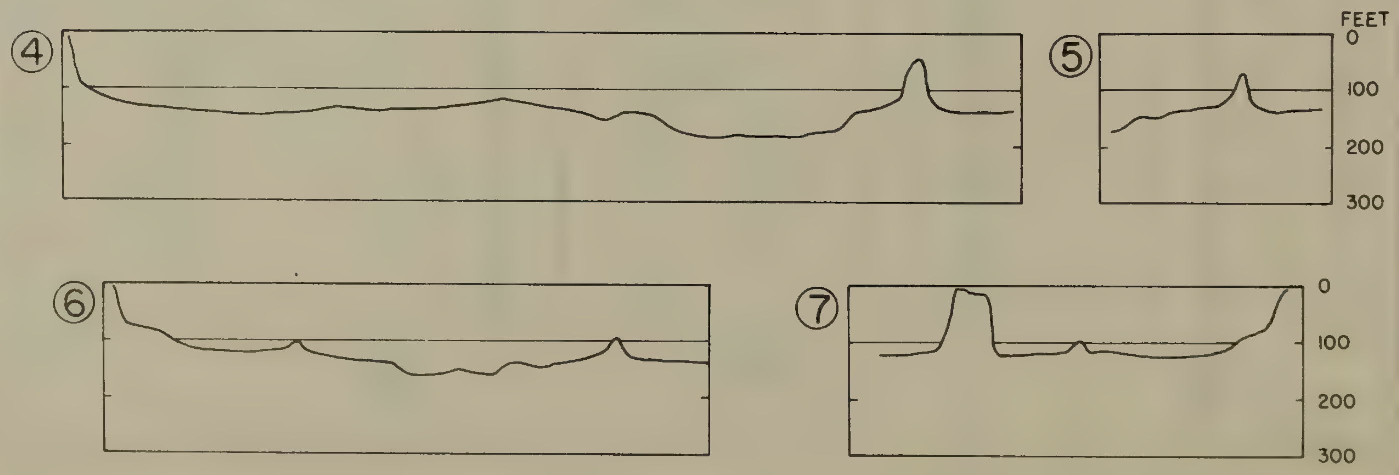


Fig. 13. Addu Atoll lagoon echosounding profiles 4-7; for location, see Figure 11, 4: D-D_1; 5: E-E_1; 6: F_1-F; 7: G_1-G. Horizontal scale approximately 1:28,000

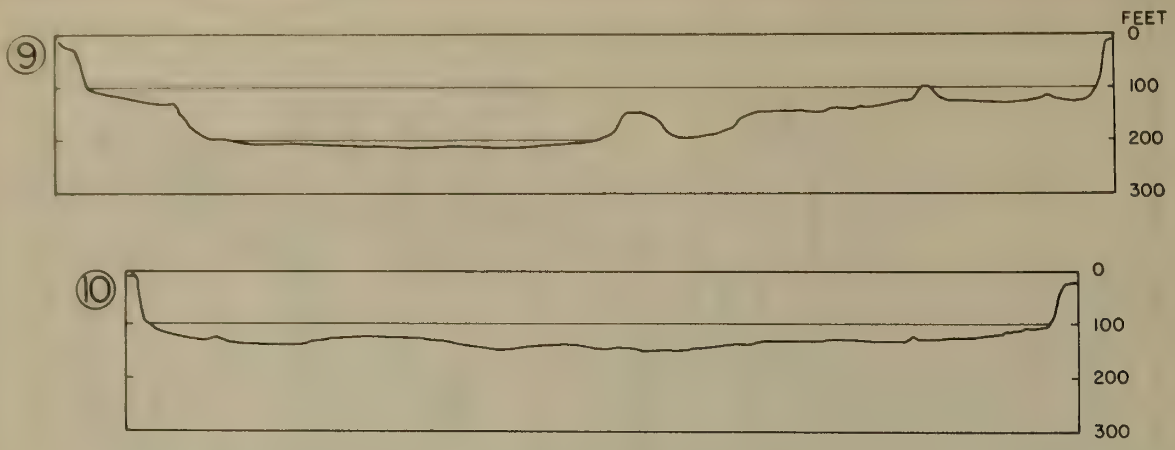


Fig. 14. Addu Atoll lagoon echosounding profiles 9-10; for location, see Figure 11, 9: J_1-J; 10, K_1-K. Horizontal scale approximately 1:27,000

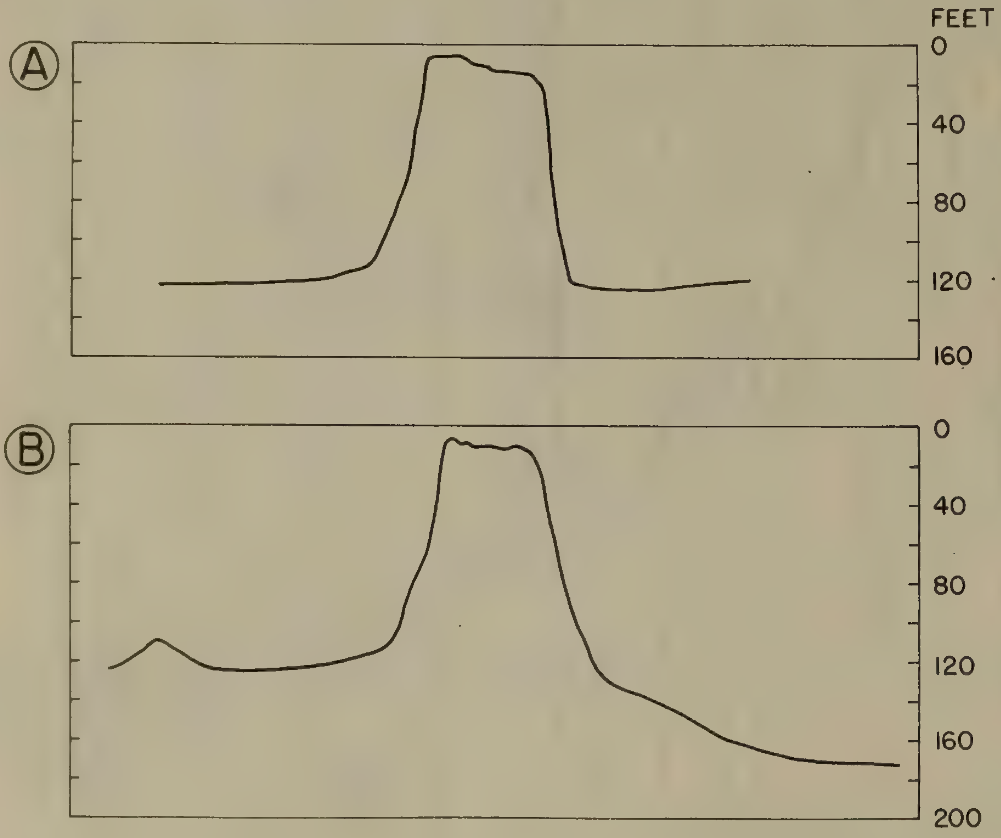


Fig. 15. Echosounding profiles of lagoon patch reef 24: (A) from profile 7, (B) from profile 8. For location, see Figure 11, A: G_1-G; B: H-H_1. The diameter of the summit is approximately 220 metres.

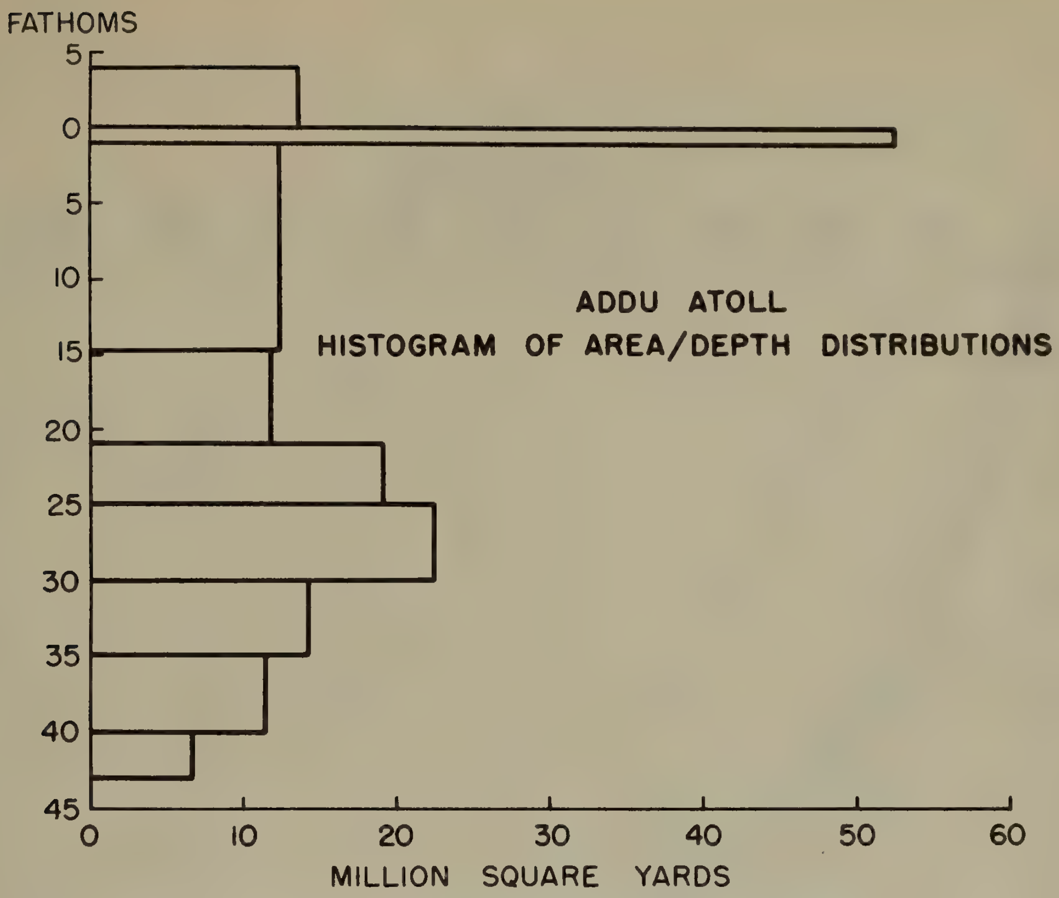


Fig. 16. Histogram showing area-depth distributions in Addu Atoll lagoon and peripheral reefs.

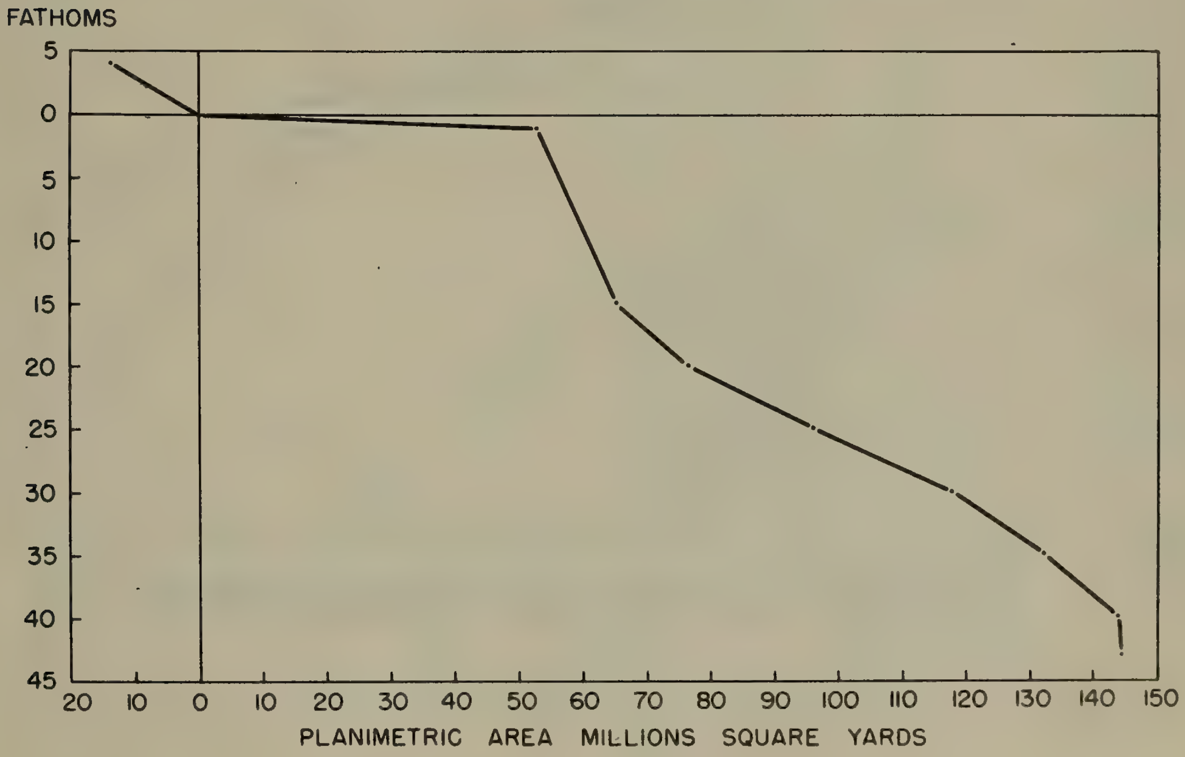


Fig. 17. Hypsometric curve for Addu Atoll lagoon and peripheral reefs.

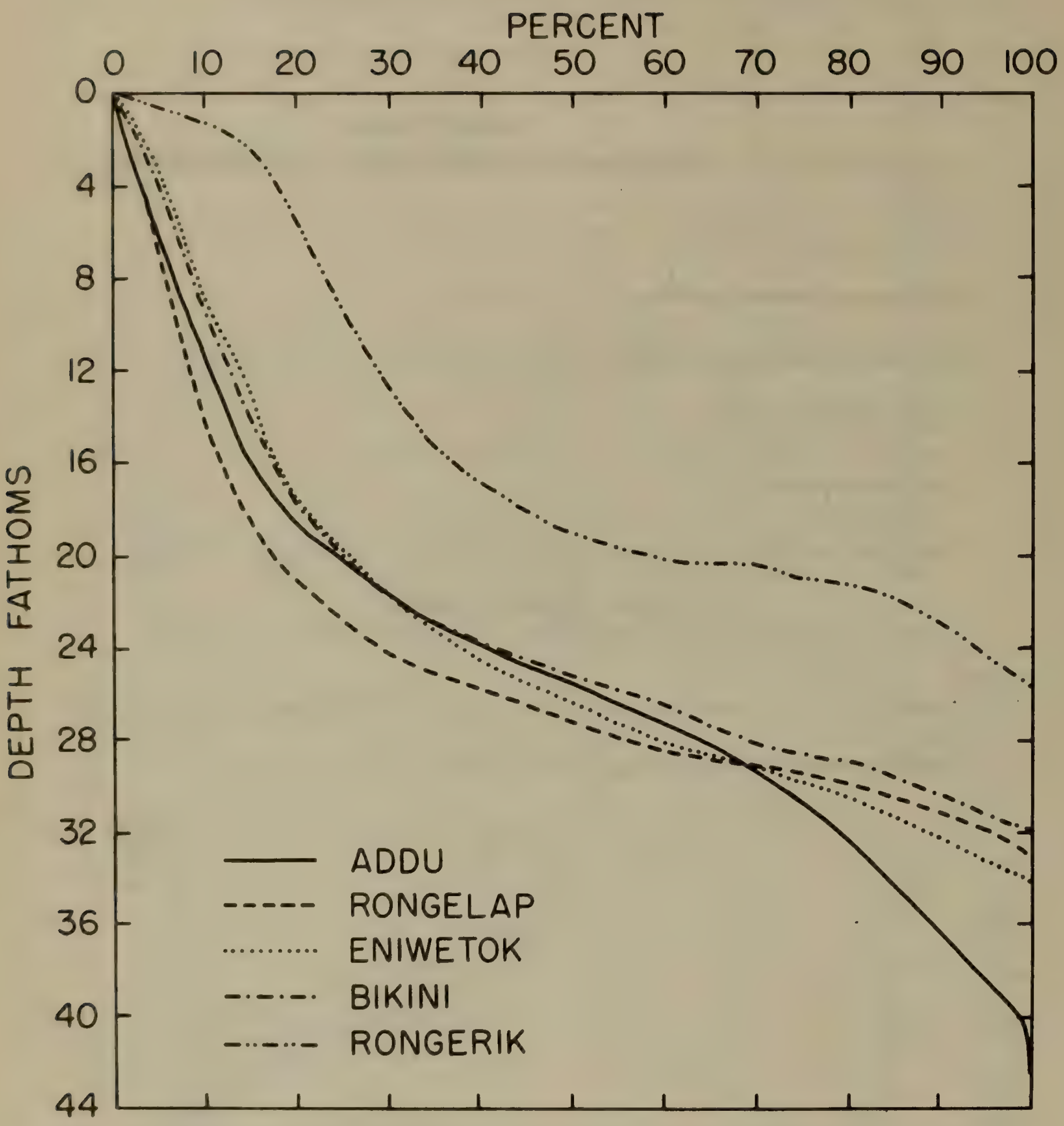
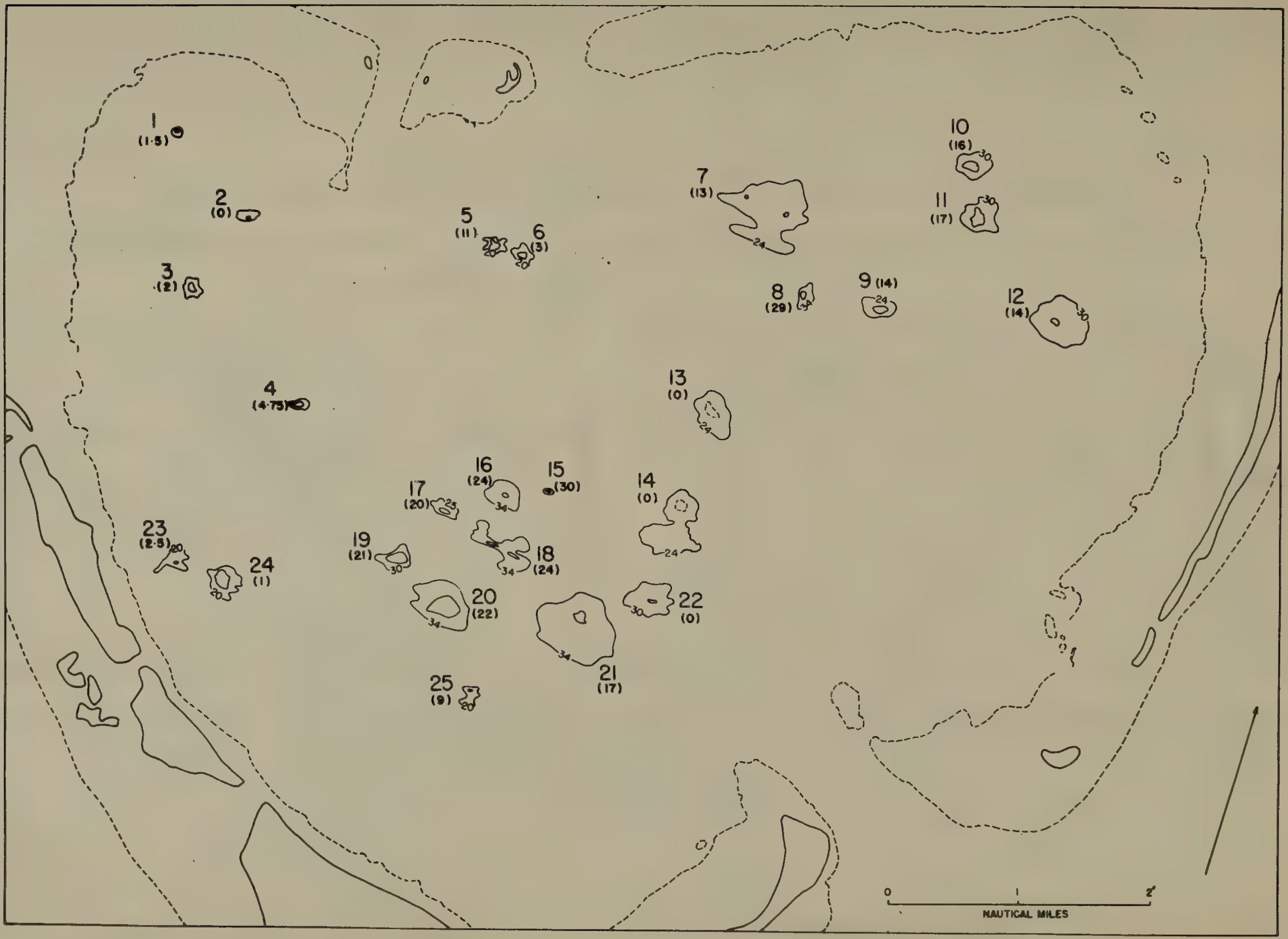


Fig. 18. Percentage hypsometric curves for Addu, Rongelap, Eniwetok, Bikini and Rongerik Atolls. Data for the Marshall Islands from Emery, Tracey and Ladd (1954).



1 (1·5)
2 (0)
3 (2)
4 (4·75)
5 (11)
6 (3)
7 (13)
8 (29)
9 (14)
10 (16)
11 (17)
12 (14)
13 (0)
14 (0)
15 (30)
16 (24)
17 (20)
18 (24)
19 (21)
20 (22)
21 (17)
22 (0)
23 (2·5)
24 (1)
25 (9)
0
1
2
NAUTICAL MILES

Fig. 19. Location and index numbers of Addu Atoll lagoon patch reefs and knolls, defined by their lowest closed contour. The small figure in brackets is the minimum recorded summit sounding, Based on the chart by Daugleish (1923).

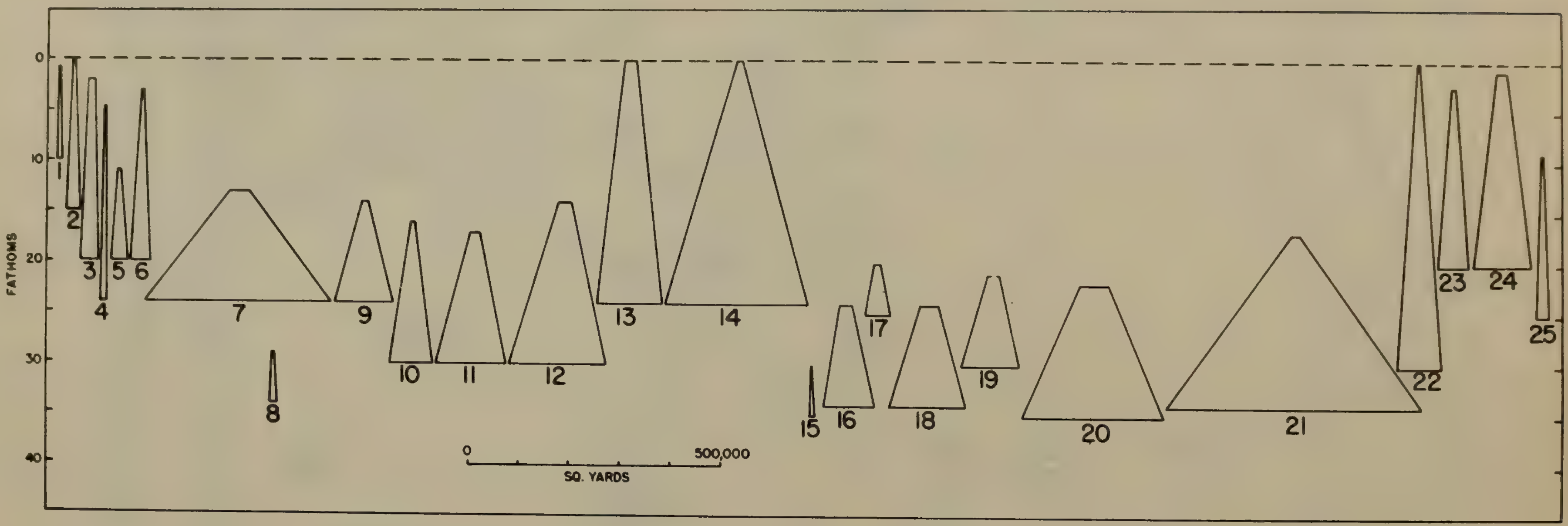


Fig. 20. Depth-area distribution of Addu lagoon patch reefs and knolls.

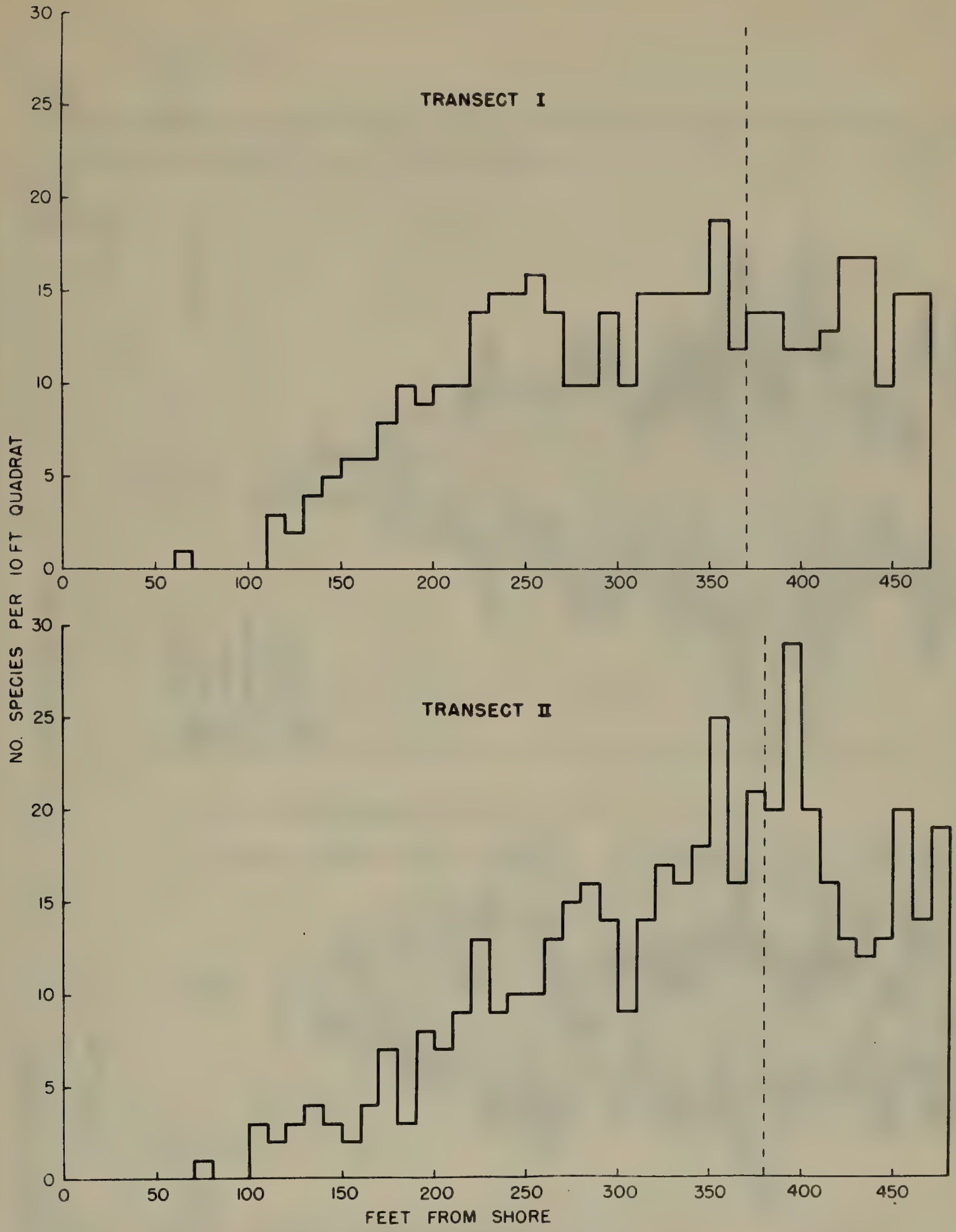


Fig. 21. Distribution of number of coral species across Gan lagoon reef transects I and II, based on field determinations of species collected in 10 ft quadrats.

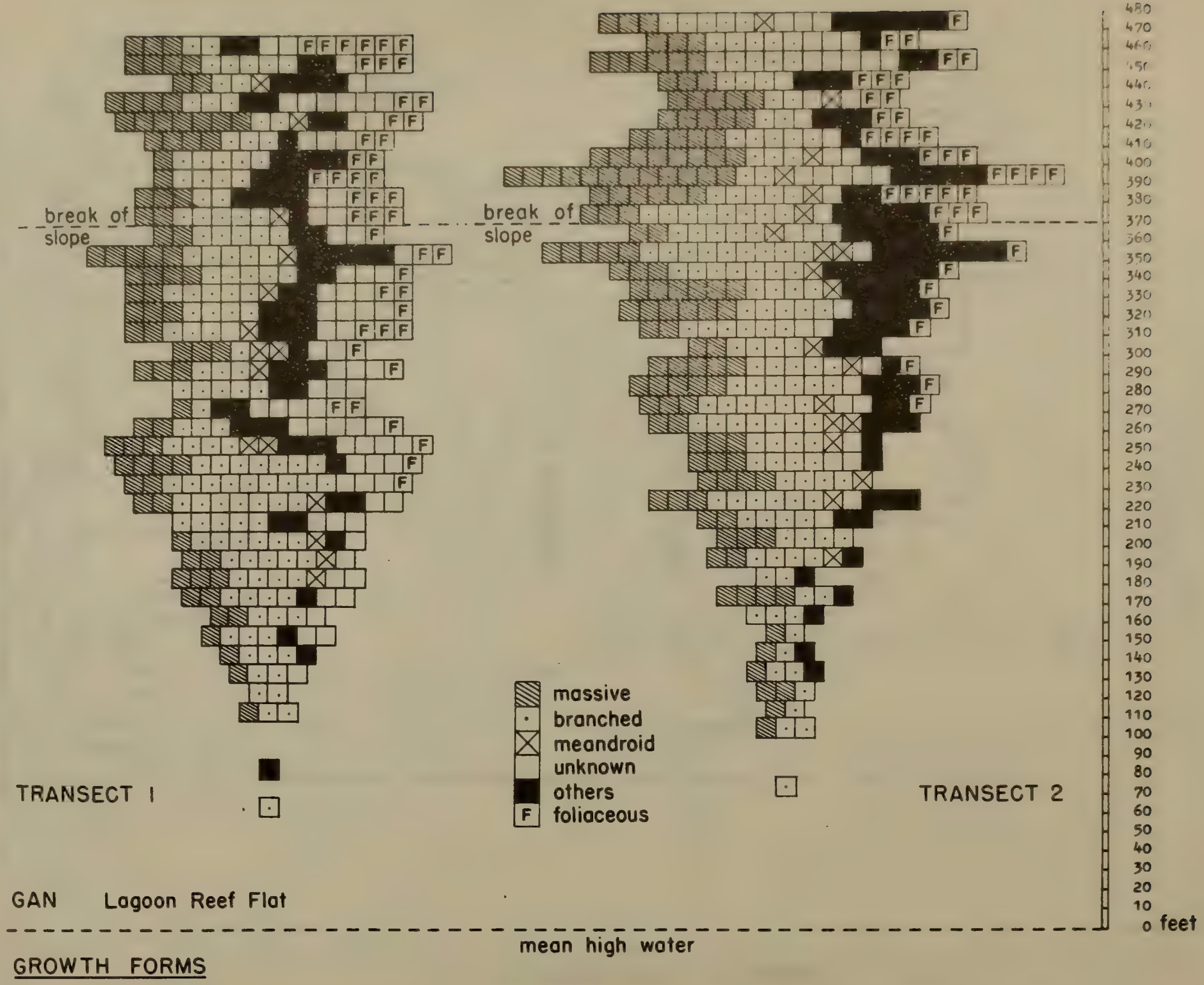


Fig. 22. Distribution of growth form of corals across Gan lagoon reef transects I and II.

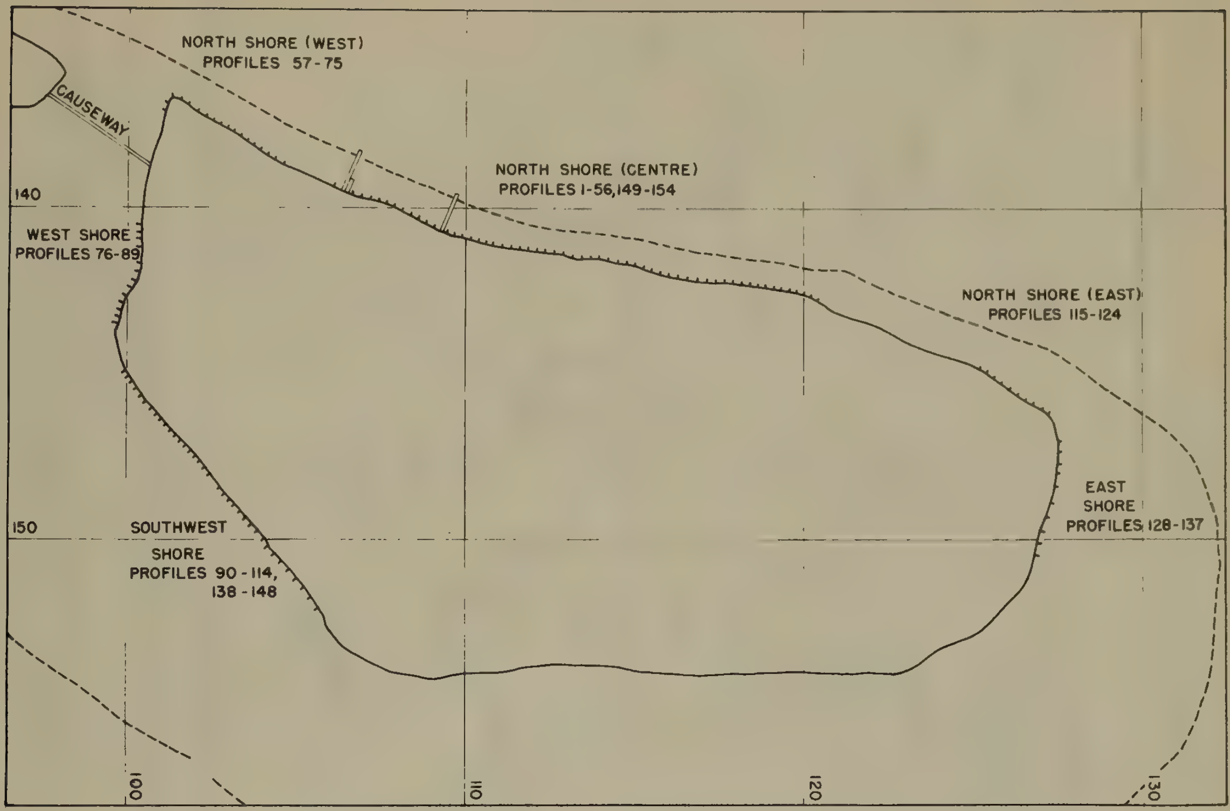

NORTH SHORE (WEST)
PROFILES 57-75
CAUSEWAY
NORTH SHORE (CENTRE)
PROFILES 1-56,149-154
140
WEST SHORE
PROFILES 76-89
NORTH SHORE (EAST)
PROFILES 115-124
EAST
SHORE
PROFILES 128-137
150
SOUTHWEST
SHORE
PROFILES 90-114,
138-148
100
110
120
130

Fig. 23. Location of beach sectors and beach profiles at Gan Island.

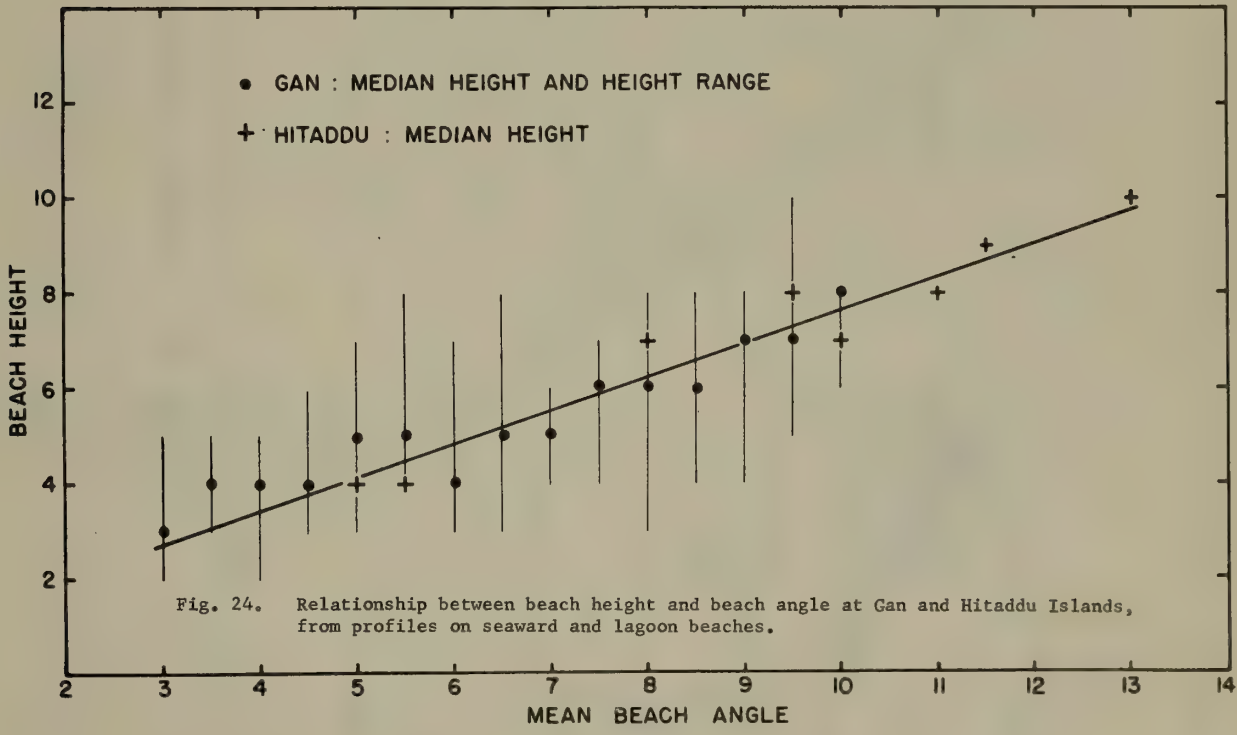


Fig. 24. Relationship between beach height and beach angle at Gan and Hitaddu Islands, from profiles on seaward and lagoon beaches.

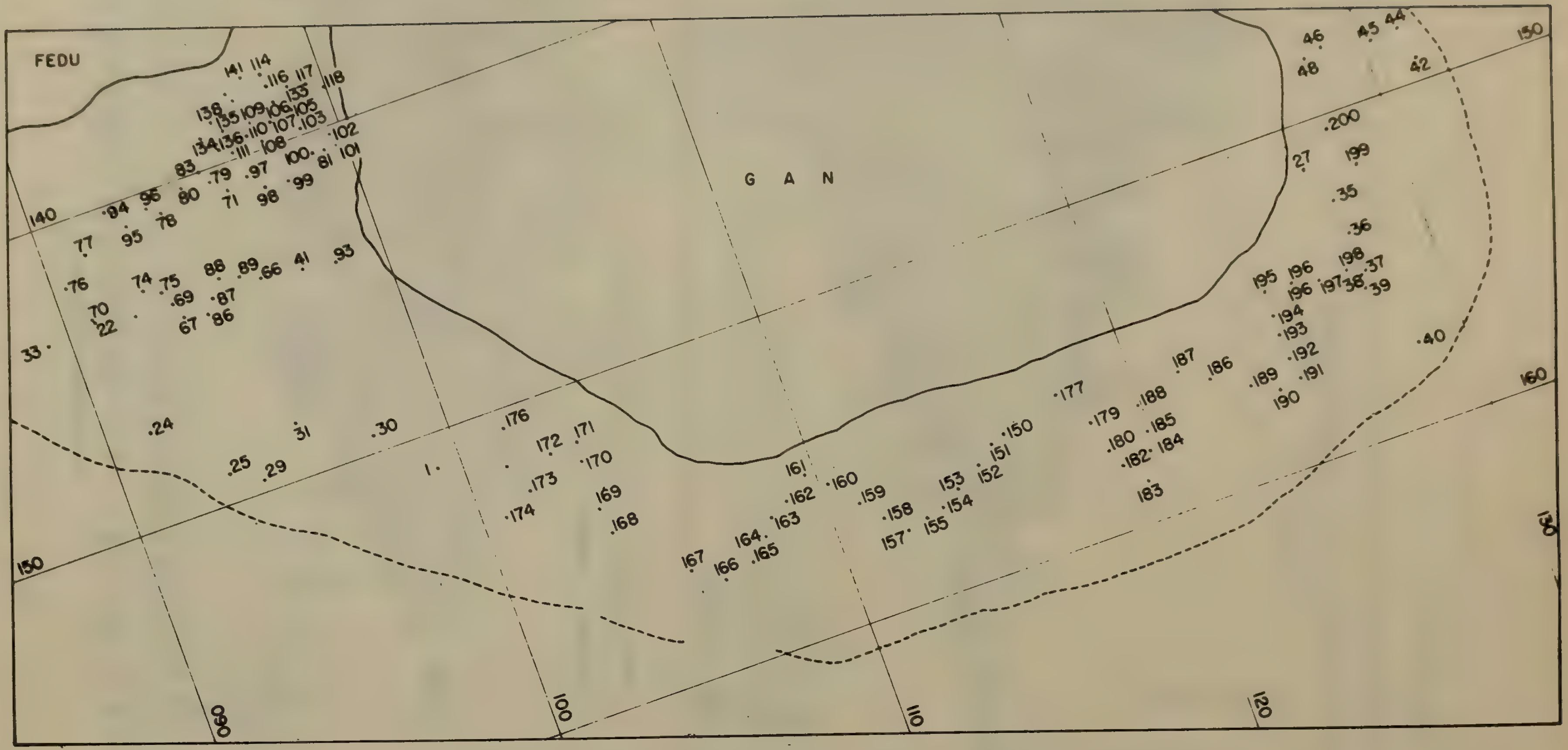

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Fig. 25. Sediment sampling stations, seaward reef flat, Gan Island.

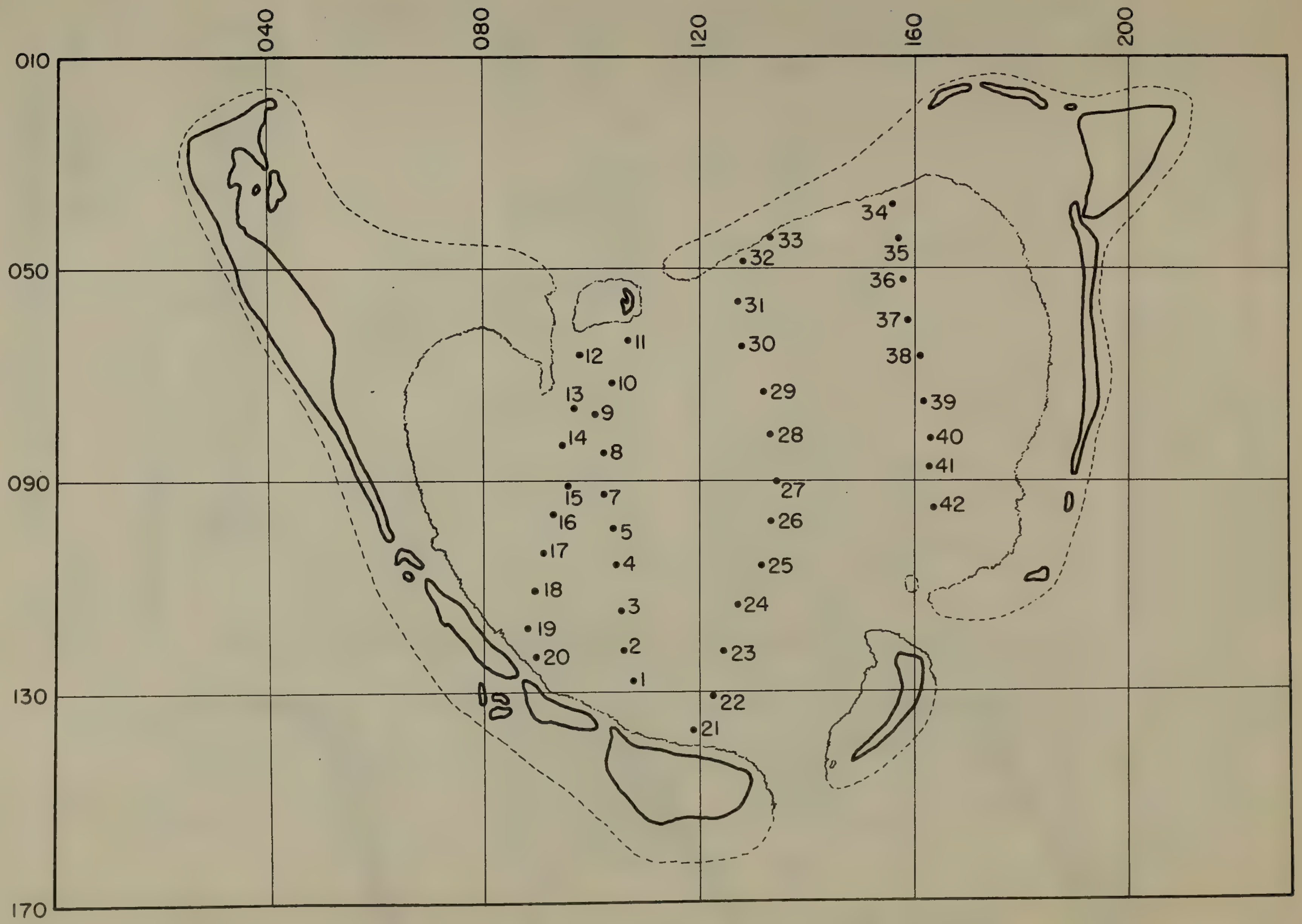
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Fig. 26. Sediment sampling stations, lagoon floor, Addu Atoll.

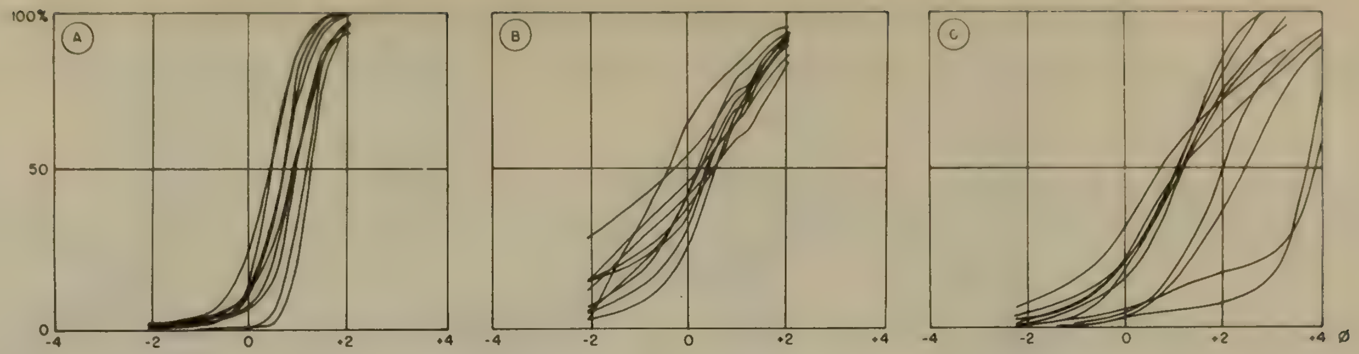

Fig. 27. Sample cumulative frequency curves for (A) Gan beach, (B) Gan seaward reef flat, and (C) Addu lagoon floor sediment samples.

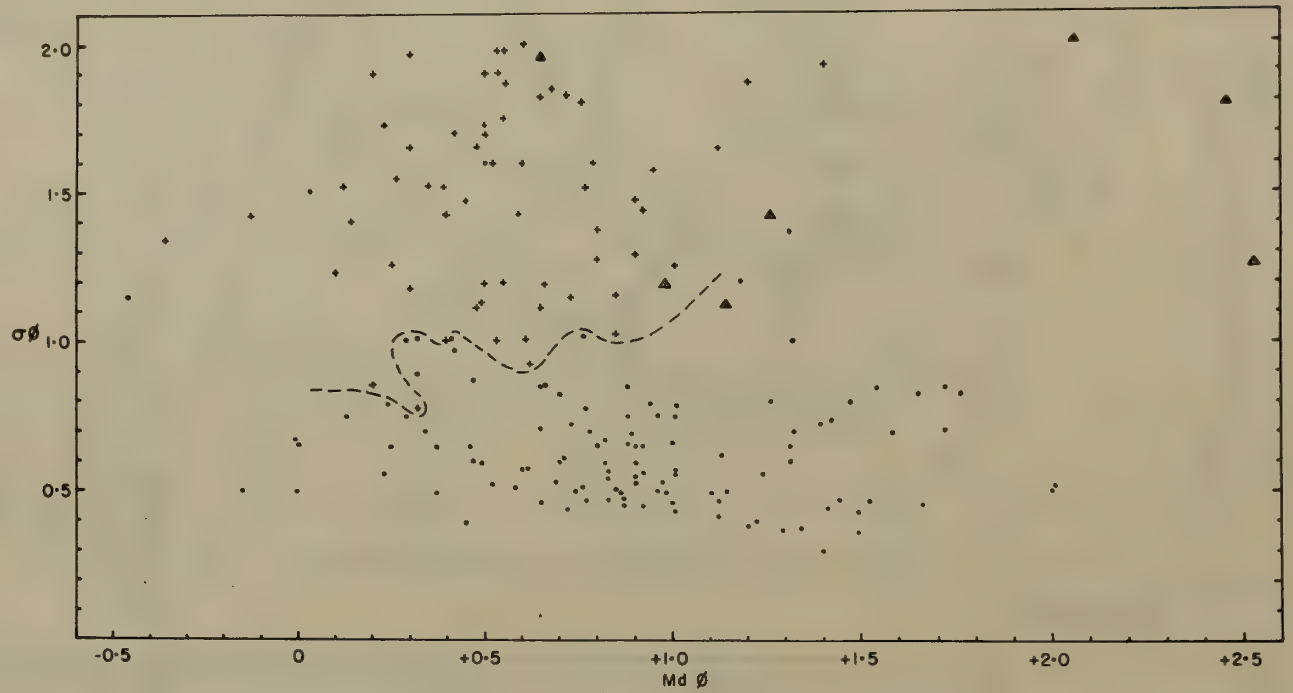

Fig. 28. Relationship betwen median size and sorting in sediment samples from Gan beaches (dots), Gan seaward reef flat (crosses), and Addu lagoon floor (triangles).

IV. PRELIMINARY LIST OF STONY CORALS FROM ADDU ATOLL

by

J. W. Wells and P. Spencer Davies

During the course of the quadrat transect surveys on the lagoon reef at Gan (see p. 28) a collection of corals was assembled. The method adopted was as follows: Each coral specimen removed and recorded from each quadrat was given a number to form the nucleus of a type collection. Subsequent corals were then compared with the types and assigned the relevant number. Any showing morphological differences from the type were given a new number and incorporated in the collection; this involved some duplication and the assemblage of a number of what later turned out to be growth forms and varieties of the same species. In this way it was possible to pinpoint the distribution of all corals collected along transects from the shore to the base of the lagoon slope. Collections were also made in a non-systematic manner whenever any corals were recognized as being not represented in the type collection. The collection therefore includes a few species which were collected on a shoal in Addu lagoon (no. 4, fig. 19) and on the seaward reef slope of the reefs to the north of the atoll.

Distribution has been related in the list to the reef terminology adopted by Tracey _et al._ (1955). On the lagoon reef flat, the area of living coral (which commences approximately one-third of the distance to the reef margin from the shore) has been divided into three arbitrary zones, _viz._: _inner_, _mid_ and _outer_. These have no ecological significance and are used solely to give greater precision in describing distribution.

Subclass	ZOANTHARIA
Order	SCLERACTINIA
Suborder	ASTROCOENIINA
Family	ASTROCOENIIDAE
Subfamily	Astrocoeniinae

Genus STYLOCOENIELLA

1) _Stylocoeniella guentheri_ (Bassett-Smith)
   Lagoon slope, Gan. 20 to 80 ft.depth

Family THAMNASTERIIDAE

Genus PSAMMOCORA

1) _Psammocora nierstraszi_ v.d. Horst
   Outer zone of lagoon reef flat, Gan.

2) _P._ (_Stephanaria_) _folium_ Umbgrove
   Outer zone of lagoon reef flat, Gan.

3) P. (Stephanaria) togianensis Umbgrove
Lagoon slope, Gan. 20-70 ft. depth

4) P. (Stephanaria) sp. cf. P.(S). digitata M.E. & H.
Lagoon reef flat, Gan.

5) P. (Plesioseris) haimeana M.E. & H.
Outer zone, lagoon reef flat, Gan. Common.

Family POCILLOPORIDAE

Genus STYLOPHORA

1) Stylophora pistillata (Esper)
Mid to outer zone, lagoon reef flat, Gan.

2) Stylophora mordax (Dana)
Seaward reef slope, off Bushy Island, N. Addu. Depth 20 ft.

3) Stylophora subseriata (Ehrenberg)
Lagoon slope, Gan. Depth 70-80 ft.

Genus SERIATOPORA

1) Seriatopora angulata Klunzinger
Seaward reef slope off Bushy Island, N. Addu. Depth 20 ft.
Not recorded from reefs at Gan.

Genus POCILLOPORA

1) Pocillopora eydouxi M.E. & H.
Lagoon reef margin, Gan. Common.

2) Pocillopora meandrina Dana var. nobilis Verrill
Outer zone of lagoon reef flat and lagoon slope to 60 ft., Gan. Very common.

3) Pocillopora damicornis (Linn.)
Very common over whole of lagoon reef flat, Gan. One of the first corals found on the landward margin of growing coral on the reef flat.
P. sp. cf. P. damicornis (Linn.) - Stunted growth form.
Inner zone of lagoon reef flat, Gan.

4) Pocillopora ligulata Dana
Lagoon slope, Gan. Depth 10-90 ft.

5) Pocillopora acuta Lamarck
Lagoon slope, Gan. Depth 40-90 ft.

Family ACROPORIDAE

Genus ACROPORA

1) *Acropora convexa* (Dana)
Found over whole surface of lagoon reef flat, Gan. Particularly abundant at lagoon reef margin.
A. sp. cf. *A. convexa* (Dana)
mid zone of lagoon reef flat, Gan.

2) *Acropora intermedia* (Brook)
Mid zone lagoon reef flat, Gan.

3) *Acropora humilis* (Dana)
Very common on whole of lagoon reef flat and to 15 ft. on lagoon slope, Gan. Also found in shallow pools behind algal pavement seaward reef flat, Gan and Hitaddu.

4) *Acropora hemprichi* (Ehrenberg)
Lagoon reef margin and to depth of 20 ft on lagoon slope, Gan. Common at depths of 20 ft on seaward reef slope of Northern reefs, Addu.

4a) *Acropora abrotanoides* (Lamarck)
Outer zone of lagoon reef flat, Gan.

5) *Acropora formosa* (Dana)
Very common. Forms a distinct zone between mid and outer zone of lagoon reef flat. A similar species, tentatively identified as *Acropora* sp. cf. *A. formosa* is dominant over large areas of the lagoon slope, between 20 and 70 ft. Gan.

6) *Acropora hyacinthus* (Dana) "cytherea" form
Lagoon reef margin, Gan.

7) *Acropora forskali* (Ehrenberg)
Lagoon reef margin, Gan.

8) *Acropora palifera* (Lamarck)
Not recorded on Gan reefs but abundant, in places dominant, on reef top and seaward margins of Northern reefs, Addu.

9) *Acropora eurystoma* (Klunzinger)
Mid zone, lagoon reef flat, Gan.

10) *Acropora variabilis* (Klunzinger)
Lagoon slope, Gan. Depth 50-80 ft.

11) *Acropora corymbosa* (Lamarck)
Lagoon reef margin and lagoon slope to 50 ft. Gan.

12) *Acropora syringodes* (Brook)
Lagoon reef margin and lagoon slope to 80 ft. Gan.

13) *Acropora* sp. cf. *A. conigera* (Dana)
Outer zone, lagoon reef flat, Gan.

14) *Acropora rotumana* (Gardiner)
Outer zone, lagoon reef flat, Gan.

15) *Acropora hystrix* (Dana)
Lagoon slope, Gan. Depth 80 ft.

16) *Acropora squarrosa* (Ehrenberg)
Lagoon slope, Gan. Depth 30 ft.

17) *Acropora* n. sp. ?
"Five Fathom Shoal", Addu Lagoon. Depth 70 ft.

Genus ASTREOPORA

1) *Astreopora myriophthalma* (Lamarck)
Lagoon reef flat and lagoon slope to 35 ft, Gan. Also recorded from "Five Fathom Shoal", Addu Lagoon. Depth 50 ft.

2) *Astreopora ocellata* Bernard
Lagoon reef flat, mid zone to reef margin and to depth of 20 ft on lagoon slope. Gan.

3) *Astreopora listeri* Bernard
Lagoon slope, Gan. Depth 15 ft.

4) *Astreopora* sp. cf. *A. gracilis* Bernard
Lagoon slope, Gan. Depth 65 ft.

5) *Astreopora* sp. cf. *A. incrustans* Bernard
Lagoon slope, Gan. Depth 40 ft.

Genus MONTIPORA

1) *Montipora sinensis* Bernard
Lagoon reef margin, Gan.

2) *Montipora danae* M.E. & H.
Lagoon slope, Gan. Depth 90 ft.

3) *Montipora pulcherrima* Bernard
Lagoon slope, Gan. Depth 90 ft.

4) *Montipora* sp. cf. *M. foliosa* (Pallas)
Lagoon slope, Gan. Depth 50 ft.

Suborder FUNGINA
Superfamily AGARICIICAE
Family AGARICIIDAE

Genus PAVONA

1) *Pavond gardineri* v.d. Horst
Lagoon slope, Gan. Depth 15 ft.

2) *Pavona clavus* (Dana)
Lagoon slope, Gan. Depth 20-60 ft.

3) *Pavona varians* Verrill
Widely distributed. Mid to outer lagoon reef flat and lagoon slope to depth of 80 ft. Gan.
var. "repens"
Lagoon slope, Gan. Depth 60-80 ft.

4) *Pavona* (*Polyastra?*) *acuticarinata* (Umbgrove)
Lagoon slope, Gan. Depth 50 ft.

5) *Pavona* (*Polyastra*) sp. cf. *P.* (*P.*) *planulata* (Dana)
Lagoon reef margin to 80 ft on lagoon slope, Gan.

6) *Pavona* (*Polyastra?*) *ponderosa* (Gardiner)
Seaward reef slope, Bushy Island. Depth 30 ft.

7) *Pavona* (*Polyastra?*) n. sp.
Lagoon slope, Gan. Depth 50 ft.

8) *Pavona* (*Polyastra*) sp.
Lagoon slope, Gan. Depth 60 ft.

9) *Pavona* (*Pseudocolumnastraea*) sp. cf. *P. maldivensis* Gardiner
Lagoon slope, Gan. Depth 60 ft.

Genus LEPTOSERIS

1) *Leptoseris gardineri* v.d. Horst
Forms large colonies in sand at base of lagoon slope, Gan.
Depth 90-100 ft.

2) *Leptoseris incrustans* (Quelch)
Lagoon slope, Gan. Depth 60 ft.

Genus PACHYSERIS

1) *Pachyseris speciosa* (Dana)
Lagoon reef margin and lagoon slope to 60 ft. Gan.

2) *Pachyseris levicollis* (Dana)
Lagoon slope Gan. Depth 40-70 ft.

3) *Pachyseris valenciennesi* M.E. & H.
Lagoon reef margin and lagoon slope to 30 ft. Gan.

Family SIDERASTREIDAE

Genus COSCINARAEA

1) Coscinaraea monile (Forskaal)
"Five Fathom Shoal", Addu Lagoon. Depth 50 ft.
Mid zone, lagoon reef flat, Gan.

Superfamily FUNGIICAE
Family FUNGIIDAE

Genus FUNGIA

1) Fungia scutaria Lamarck
Lagoon reef margin to 50 ft on lagoon slope, Gan.

2) Fungia repanda Dana
Lagoon reef margin to 90 ft on lagoon slope. Gan. Common.

3) Fungia echinata (Pallas)
Lagoon slope, Gan. Depth 70-90 ft.

4) Fungia fungites (Linnaeus)
Very common on whole of lagoon reef flat, Gan, attached stage commonly on Acropora formosa. Not recorded from lagoon slope.

Genus HERPOLITHA

1) Herpolitha limax (Esper)
Lagoon reef margin to 60 ft on lagoon slope, Gan. Common.

Genus POLYPHYLLIA

1) Polyphyllia talpina (Lamarck)
Lagoon floor at base of lagoon slope, depth 80-100 ft.
Gan and Northern reefs, Addu. Tentacles extended during day.

Genus HALOMITRA

1) Halomitra philippinensis Studer
Lagoon slope, Gan. Depth 50-90 ft. Common.

Superfamily PORITICAE
Family PORITIDAE

Genus GONIOPORA

1) Goniopora minor Crossland
Lagoon reef margin to 80 ft on lagoon slope, Gan.

2) Goniopora sp. aff. G. planulata (Ehrenberg) cf. Klunzinger
Seaward reef slope, Bushy Island. Depth 30 ft.

Genus PORITES

1) Porites solida (Forskaal)
No distribution data available.

2) Porites lutea M.E. & H.
Lagoon slope, Gan. Depth 10-100 ft.

3) Porites lichen Dana
Lagoon slope, Gan. Depth 90 ft.

4) Porites sp. cf. P. alveolata
Outer zone, lagoon reef flat, Gan.

5) Porites (Synaraea) monticulosa (Dana)
Lagoon slope, Gan. Depth 15-90 ft.

6) Porites (Synaraea) n. sp.? aff. P.(S.) horizontalata Hoffmeister
Lagoon slope, Gan. Depth 70 ft.

7) Porites sp. (cf."P. mauritius 5" Bernard)
Seaward reef edge, Gan.

Genus ALVEOPORA

1) Alveopora sp. cf. A. viridis (Quoy & Gaimard)
Lagoon slope, Gan. Depth 70 ft.

Suborder	FAVIINA
Superfamily	FAVIICAE
Family	FAVIIDAE
Subfamily	Faviinae

Genus CAULASTREA

1) Caulastrea furcata Dana
Mid zone of lagoon reef flat, Gan.

2) Caulastrea tumida (Matthai)?
"Five Fathom Shoal", Addu Lagoon. Depth 50 ft.

Genus PLESIASTREA

1) Plesiastrea versipora (Lamarck)
Lagoon slope, Gan. Depth 80 ft. "Five Fathom Shoal",
Addu Lagoon. Depth 70 ft.

Genus FAVIA

1) *Favia valenciennesi* (M.E. & H.)
   Lagoon reef flat, Gan.

2) *Favia rotumana* (Gardiner)
   Lagoon reef flat, Gan.
3) *Favia stelligera* (Dana)
   Lagoon reef margin, Gan.

4) *Favia favus* (Forskaal)
   Inner zone of lagoon reef flat to 40 ft on lagoon slope, Gan. Also mid zone, lagoon reef flat, Gan.

5) *Favia pallida* (Dana)
   Mid zone of lagoon reef flat to 30 ft on lagoon slope, Gan.

6) *Favia hululensis* Gardiner
   Mid zone, lagoon reef flat, Gan.

7) *Favia speciosa* (Dana)
   Lagoon reef flat, mid zone, to 80 ft on lagoon slope, Gan.
   Also at depth of 60 ft on "Five Fathom Shoal", Addu Lagoon.
   F. speciosa Dana "clouei" form
   Lagoon slope 80 ft, Gan.
   F. sp. cf. *F. speciosa* Dana
   "Five Fathom Shoal", Addu Lagoon. Depth 60 ft.

Genus FAVITES

1) *Favites melicerum* (Ehrenberg)
   Mid zone of lagoon reef flat, Gan.

2) *Favites halicora* (Ehrenberg)
   Lagoon slope, Gan. Depth 50-80 ft.
   F. sp. cf. *F. halicora* (Ehrenberg)
   Lagoon reef margin and to 80 ft on lagoon slope, Gan.

3) *Favites ehrenbergi* (Klunzinger)
   Lagoon slope, Gan. Depth 50-60 ft.

4) *Favites hemprichi* (Ehrenberg)
   Mid zone of lagoon reef flat, Gan.

5) *Favites complanata* (Ehrenberg)
   Lagoon reef margin, Gan.

6) *Favites pentagona* (Esper)
   Lagoon slope, Gan. Depth 80 ft.

7) *Favites abdita* (Ellis & Solander)
   Mid and outer zone of lagoon reef flat and to 70 ft on lagoon slope, Gan.

8) *Favites flexuosa* (Dana)
Lagoon slope, Gan. Depth 15-90 ft.

Genus OULOPHYLLIA
1) *Oulophyllia crispa* (Lamarck)
Lagoon reef margin, Gan.

Genus GONIASTREA
1) *Goniastrea retiformis* (Lamarck)
Middle to outer zone, and reef margin of lagoon reef flat, Gan.
One of the commonest massive corals on this reef.
G. retiformis (Lamarck) var. *parvistella* (Dana)
Mid to outer lagoon reef flat and to 20 ft on lagoon slope, Gan.

2) *Goniastrea pectinata* (Ehrenberg)
Lagoon slope, Gan. Depth 15-80 ft. Also recorded from "Five Fathom Shoal", Addu Lagoon. Depth 50 ft.

Genus PLATYGYRA
1) *Platygyra lamellina* Ehrenberg
Outer zone, lagoon reef flat, Gan.
P. lamellina Ehrenberg *forma sinensis* (M.E. & H.)
Outer zone of lagoon reef flat, Gan.
P. lamellina Ehrenberg *forma rustica* (Dana)
Mid to outer zone of lagoon reef flat, Gan.
P. lamellina Ehrenberg *forma astreiformis* (M.E. & H.)
Outer zone of lagoon reef flat, Gan.

Genus LEPTORIA
1) *Leptoria phrygia* (Ellis & Solander)
Mid zone to reef margin of lagoon reef flat, Gan. Very common.

Genus HYDNOPHORA
1) *Hydnophora exesa* (Pallas)
Mid zone, lagoon reef flat, Gan.

2) *Hydnophora microconos* (Lamarck)
Outer zone, lagoon reef flat, Gan.

Subfamily Montastreinae

Genus DIPLOASTREA
1) *Diploastrea helipora* (Lamarck)
Lagoon slope 60 to 100 ft, Gan and Fedu. Forms massive sheets at base of lagoon slope. One such mass measured approximately 15 x 20 ft.

Genus LEPTASTREA

1) Leptastrea transversa Klunzinger
Mid zone, lagoon reef flat, Gan.

2) Leptastrea purpurea (Dana)
Mid zone, lagoon reef flat to 30 ft on lagoon slope, Gan.

Genus CYPHASTREA

1) Cyphastrea microphthalma (Lamarck)
Mid zone, lagoon reef flat to reef margin and to depth of 90 ft on lagoon slope, Gan.

Genus ECHINOPORA

1) Echinopora lamellosa (Esper)
Outer zone of lagoon reef flat to 40 ft on lagoon slope. Dominant coral in places at lagoon reef margin at Gan; less frequent at Fedu.

Family OCULINIDAE
Subfamily Galaxeinae

Genus GALAXEA

1) Galaxea fascicularis (Lamarck)
Mid to outer zone, lagoon reef flat, Gan. "Five Fathom Shoal", Addu Lagoon, depth 40 ft.

2) Galaxea clavus (Dana)
Mid zone of lagoon reef flat, reef margin and lagoon slope to 80 ft, Gan. Very common.

Genus MERULINA

1) Merulina ampliata (E. & S.)
Outer zone of lagoon reef flat and to 90 ft on lagoon slope, Gan.
M. sp. cf. M. ampliata (E. & S.) (M. regalis Dana?)
Lagoon reef margin to 40 ft on lagoon slope, Gan.

Family MUSSIDAE

Genus ACANTHASTREA

1) Acanthastrea echinata (Dana)
Lagoon slope, Gan. Depth 60 ft.

Genus CYNARINA

1) Cynarina lacrymalis (M.E. & H.)
Lagoon slope 80-100 ft, Gan.

Genus LOBOPHYLLIA

1) *Lobophyllia corymbosa* (Forskaal)
Outer zone of lagoon reef flat to 20 ft on lagoon slope, Gan.

2) *Lobophyllia costata* (Dana)
Lagoon reef flat and to 30 ft on lagoon slope, Gan.

3) *Lobophyllia* sp. cf. *L. hemprichi* (Ehrenberg)
Lagoon slope, Gan. Depth 100 ft.

4) *Lobophyllia* sp. cf. *L. fistulosa* (M.E. & H.)

Genus SYMPHYLLIA

1) *Symphyllia radians* M.E. & H.
Mid to outer zones of lagoon reef flat and to 80 ft on lagoon slope, Gan.

2) *Symphyllia* sp. cf. *S. nobilis* (Dana)
Mid zone of lagoon reef flat and to 40 ft on lagoon slope, Gan.

3) *Symphyllia valenciennesi* M.E. & H.
Lagoon slope, Gan. Depth 90 ft.

Family PECTINIIDAE

Genus ECHINOPHYLLIA

1) *Echinophyllia aspera* (E. & S.)
Lagoon slope, Gan. Depth 20-90 ft.

Genus PECTINIA

1) *Pectinia alcicornis* (Saville Kent)
Lagoon slope, Gan. Depth 60-80 ft.

Genus OXYPORA

1) *Oxypora lacera* (Verrill)
Lagoon slope, Gan. Depth 15-80 ft.

Genus MYCEDIUM

1) *Mycedium tubifex* (Dana)
Lagoon slope, Gan. Depth 50-80 ft.

Suborder CARYOPHYLLIINA
Superfamily CARYOPHYLLIICAE
Family CARYOPHYLLIIDAE
Subfamily Eusmiliinae

Genus EUPHYLLIA

1) *Euphyllia glabrescens* (Chamisso & Eysenhardt)
Mid to outer zone, lagoon reef flat, Gan.

2) Euphyllia fimbriata (Spengler)
Lagoon slope, Gan. Depth 60 ft.

Genus PLEROGYRA
1) Plerogyra sinuosa (Dana)
Lagoon slope, Gan. Depth 30-90 ft.

Suborder DENDROPHYLLIINA
Family DENDROPHYLLIIDAE

Genus DENDROPHYLLIA
1) Dendrophyllia micrantha (Ehrenberg)
In sand at base of lagoon slope, Gan. Depth 100-110 ft.

Genus TUBASTRAEA
1) Tubastraea aurea (Quoy & Gaimard)
Beneath overhangs, in shade on dead boulders, lagoon reef margin, Gan.

2) Tubastraea diaphana (Dana)
Similar distribution to T. aurea.

Genus TURBINARIA
1) Turbinaria peltata (Esper)
From wrecked ship, Addu Lagoon. Depth 110 ft.
"Five Fathom Shoal", Addu Lagoon. Depth 90 ft.

2) Turbinaria n. sp. ?
Lagoon slope, Gan. Depth 50 ft.

Subclass ALCYONARIA
Order COENOTHECALIA
Family HELIOPORIDAE

Genus HELIOPORA
1) Heliopora coerulea (Pallas) var. meandrina Dana
Inner reef zone, lagoon reef flat, Gan.

Class HYDROZOA
Order MILLEPORINA
Family MILLEPORIDAE

Genus MILLEPORA
1) Millepora latifolia Boschma
Outer zone of lagoon reef flat, and to 20 ft on lagoon slope, Gan.

2) Millepora tenera Boschma
Lagoon reef margin and to 80 ft on lagoon slope, Gan.

Order	STYLASTERINA
Family	STYLASTERIDAE
Subfamily	Distichoporinae

Genus DISTICHOPORA

1) Distichopora fisheri Broch
In shaded areas on dead coral boulders, lagoon reef margin, Gan.

V. VEGETATION AND FLORA

A. A brief history of botanical observations and collections made in the Maldive Islands, Indian Ocean

by E. W. Groves [*]

Although the earliest known account of the Maldives is that given by the Moorish traveller, Ibn Batutah (1829, 1853-59) who was in the islands in 1343-44 and briefly mentioned pomegranates (*Punica granatum* L.) in cultivation there, it was not until nearly 300 years later that the first description of any of the vegetation was made. This was recorded by a Frenchman, Pyrard de Laval, who whilst travelling to the East Indies in the barque "Corbin", was shipwrecked on one of the northern islands of the group during July 1602. He stayed on in the Maldives from 1602 to 1607 and it was during this period that he made notes for an account of the islands which he subsequently published on his return to France (Pyrard, 1679). His references to the vegetation were, however, confined to describing plants that he had noticed either in cultivation or being put to some domestic use.

The first collection of plants, albeit somewhat fragmentary and few in number, was made by H.C.P. Bell, a Ceylon Civil Servant, during the first of his visits to Malé (the capital of the Maldives) in 1879. The few specimens he brought back from this trip were examined by W. Ferguson of Colombo. Bell incorporated Ferguson's determinations along with other of his observations on plants seen in cultivation (amounting to 39 species in all) in his excellent account of the Maldive Islands and its people which was published by the Ceylon Government a few years later (Bell, 1883).

Capt. A. C. Christopher, serving in a British Naval warship, visited Malé in 1888 making a collection of flowering plants (both wild and cultivated) amounting to 73 species of which 44 were new to Bell's previous list. A few more additions were discovered later by a Mr.Haly, at that time Director of the Colombo Museum, visiting the same island in 1893. Both collections were reported upon by Henry Trimen (1896). In 1896, Mohammed Ibrahim Didi, then Prime Minister to the Sultan of the Maldives, despatched to the Peradeniya Gardens herbarium a collection he had made of some 174 numbers including many cultivated species. These he had collected probably all from Malé or Funadu islets, both on Malé atoll and included 100 species new to the Maldive list. Three further brief visits to the same atoll were made during the next few years: the first by J. J. Thorburn in Aug. 1901 when he made notes of some of the economic plants under cultivation there; the second by Capt. Simons of the British warship "Pomone" who recorded another three new species; and the third by F. Lewis of the Ceylon Forestry Dept. who visited Malé and two adjacent islands in Oct. 1901 and was able to add yet a further seven records. All these additions were taken into account in the Willis and Gardiner paper mentioned below.

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The first widely gathered botanical collection was not made in the Maldives until the visit of the J. Stanley Gardiner expedition[*] to Minikoi and the Maldives during 1899-1900. In the course of this expedition, the primary purpose of which was to study the reef formations and their associated fauna and flora, collections were made on 19 atolls from Ihavandifulu in the north to Addu in the south. About 212 different species including flowering plants and ferns were collected and presented to the herbarium at Peradeniya Gardens, Ceylon. The marine algae that were collected were brought back to England and presented to the herbarium at Cambridge University. They were determined and published upon as follows: the calcareous algae 9 species belonging to 4 genera were dealt with by M. Foslie (1903) and the remainder which included 4 species from Suvadivan waters and 2 species from Addu Atoll were written up by Miss E. Barton (1903). The vascular plants were determined in Ceylon by W. de Alvis and J. C. Willis and were written up, along with those smaller collections mentioned above, in an excellent account by the latter in conjunction with J. Stanley Gardiner (Willis & Gardiner, 1901). Thus by the end of 1909 the vascular flora list for the islands had risen to 284 species.

Although a few visits were made to the islands between the two World wars the only known reference to any plants is that given by T.W. Hockley in his book (1935) which gives an account of his trip, to Male in particular, in 1926. He mentions some of the species grown or used economically but all of these had already been mentioned by earlier authors. During World War II the present author (E. W. Groves) was stationed at Addu Atoll from 1943 to 1945 during which time he made a small collection of flowering plants and some notes of some of the species seen growing on Gan and a few on Fedu and Hittadu. Owing to insect ravage two specimens only survived to be determined but these together with those identifiable from his notes amounted to 18 species of which 3 species were new Maldive records. These were *Canavalia cathartica*,[**] *Commelina suffruticosa* and *Cyanotis axillaris*, all from Gan island.

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[*] J. S. Gardiner was a Fellow of Cambridge University and his expedition, consisting of himself as leader, with L. A. Borradaile from June-July 1899 and C. Forster Cooper from Oct. 1899-April 1900, was under patronage from the Royal Society and the British Association.

[**] Seeds of *Canavalia cathartica* were brought back to England in 1945 and taken to the Chelsea Physic Garden, London. These were germinated in 1946 under tropic heat and by that midsummer two vines at least were trailing along beams of the glass house for about 15 ft. Unfortunately a countrywide fuel shortage the following winter prevented the stoves being maintained at the necessary temperature and the *Canavalia*, along with many other plants that were in the tropic house at the time, perished.

In April 1956 F. R. Fosberg paid a short visit to Malé atoll and whilst there made a good collection of flowering plants both on Malé island itself and on two adjacent islands (Kudos Bados and Furannafuri). In addition notes were made of species identified in the field but not actually collected, especially of plants in cultivation in gardens on Malé. A later assessment of specimens both collected and identified on sight indicated a further 44 species not already known from the Maldives. These were listed together with a detailed ecological account of the islands visited in a paper published by Fosberg (1957). W. W. A. Phillips who was in the Maldives first at Malé, Nov. 1956-Feb. 1957, and then on Gan island, Addu Atoll, May 1958-April 1959, made a small collection during his first stay which he sent for identification to A.S.A. Packeer (Asst. Warden, Dept. of Wild Life) in Colombo. The list of 12 species was included in Fosberg's paper just mentioned.

During Sept. and Oct. 1957 the Yale University Seychelles expedition en route there from Colombo visited North Malé, Fadiffolu, South Mahlosmadulu and Addu atolls. At a prior request W. D. Hartman, one of the zoologists on the expedition, collected as many different Pandanus spp. as he encountered and as a result a small but excellent collection was brought back to the Arnold Arboretum herbarium for Dr. H. St. John to study. After evaluation 4 species new to science and to the Maldive list were described (St. John, 1961).

As far as known, the next and most recent collections made in the Maldives are those of the 1964 expedition, reported upon below in parts C and D.

B. Preliminary account of the land and marine vegetation of Addu Atoll

by D. C. Sigee

There are few studies of the vegetation of the Maldives, and even less attention has been paid to that of Addu Atoll. Earlier papers were mostly systematic lists of plants. In addition to such a list, Willis and Gardiner (1901) include much information on plant distribution, economic uses and vegetation of the Maldive Islands. Gardiner (1903, p. 25) noted that the luxuriance of the vegetation of the Maldives tended to increase with rainfall from North to South. Both Agassiz (1903, p. 146) and Sewell (1936a) comment on Addu vegetation.

During the 1964 expedition, collections of land and marine flora and notes on the vegetation were made at Gan and Hitaddu Islands. The other islands could not be visited, but Midu and Maradu are described in some detail by Willis and Gardiner (1901, p. 78-80). Gan was described as"well-wooded" by Sewell (1936a, p. 80), and remained so at least until 1940 (West coast of India Pilot, 1961, p. 58). During World War II, much of the vegetation was removed when an airstrip and installations were built, and a second major phase of clearing took place in 1957, when the present staging post was established. There is little undisturbed vegetation left at Gan therefore, but in recent years there has been considerable opportunity for additions to the flora of imported species, both weeds and cultivated plants. Similar, though less extensive, clearing has taken place on the southern part of Hittadu. Conditions are therefore comparable with those of other airstrip atolls in the Pacific, such as Midway and Wake. About 142 species of land plants were collected at Addu Atoll in 1964, and these are reported in Chapter V, part C. About 100 species of algae were collected and were identified by R. Tsuda and J. Newhouse (Chapter V, part D).

Land vegetation of Gan Island

Much of the original woodland vegetation of Gan has disappeared with recent clearing, and most of the island is now covered with open grassland, with a little open woodland in the centre of the island, and some coastal shrubs and trees. The water table is high over the whole island surface, resulting in the formation of a zone of marshland at the southeast end (Figure 29).

The open grassland is continually cleared of bushes and tall herbs by hand and mechanical activity, and is continually sprayed with tar sprays to reduce the breeding of mosquitoes. Where the water table is highest, sedges form the sward completely, _Cyperus rotundus_, _C. polystachyos_ and _Fimbristylis cymosa_ being very common. Grasses are commoner in the drier regions, comprising largely _Panicum repens_, _Digitaria timorensis_ and _Dactyloctenium aegyptium_. In some parts, where the ground is very dry, with bare patches of earth, _Sida humilis_, _Tridax procumbens_, _Corchorus aestuans_ and _Thuarea involuta_ are typical.

A variety of weeds occur in this open grassland. *Celosia argentea*, *Cassia occidentalis*, *Cyperus melanosperma*, *Physalis angulata* and *Cleome viscosa* seem particularly characteristic of this habitat.

Areas near roads and buildings are also kept clear of tall herbs and shrubs. A few trees have been left standing near the staging Post buildings at the northwest point: these include various coconut palms 30-67 ft. tall, *Terminalia catappa* 50 ft tall, *Artocarpus altilis* 35 ft tall, and *Delonix regia*. In the northern part of the island, at the site of the former Maldivian village, is an old graveyard. This contains a a single specimen of *Moringa oleifera*, and adjacent to a nearby Mosque a single large tree of *Erythrina variegata*.

In the centre of the island is a zone of woodland. Part of this is fairly dense and is probably regenerating after clearance. The woodland has well developed tree, bush, and herb layers. The tallest tree was *Eugenia cumini* averaging 44 ft in height but reaching 50 ft. *Hibiscus tiliaceus* is very common, the mature trees reaching 14-16 ft. Other trees include *Morinda citrifolia* up to 9 ft tall and *Pandanus* up to 26 ft. The shrub layer consists mainly of juvenile *Hibiscus tiliaceus*, *Morinda citrifolia* and *Pandanus*. There is little light penetration to the herb layer, where the ferns *Thelypteris goggilodus* and *Nephrolepis hirsutula* cover the ground in a dense layer. *Cyanotis axillaris* is found at the edge of the woodland, and in sunny clearings. South of the main woodland is an area of younger woodland largely consisting of juveniles reaching a height of 9 ft. *Hibiscus tiliaceus* is widespread, with *Morinda citrifolia* and *Eugenia* also occurring. *Ixora coccinea* is common. The fern layer is well developed, with the grass *Apluda mutica* occurring in the more open conditions of regenerating woodland.

In the southern part of the island, in the marshland and open scrub, clearing is not as rigorous as in the northern end. The grass *Apluda mutica* occurs extensively over the whole area, with many bushes. Many plants are found here that do not occur in the open grassland, including *Ricinus communis*, *Hedyotis brachiata*, *Ammania baccifera*, *Passiflora foetida*, *Ipomoea tuba*, *Gloriosa superba*.

Much of the marshland consists of sedges, *Cladium jamaicense*, *Cyperus ligularis*, and *C. javanicus*, to a height of 2-3 ft. Other sedges present are *Cyperus rotundus* and *C. polystachyos* and the two species of *Fimbristylis*. In the wetter areas, *Lippia nodiflora*, *Eclipta alba* and *Bacopa monnieri* are plentiful, the latter two species being found only in this region. *Apluda mutica* occurred over the whole marshland, and patches of *Thelypteris goggilodus* in the drier areas.

Around the edge of the marshland, and scattered sparsely throughout, are small shrubs of *Scaevola taccada*, *Hibiscus tiliaceus*, *Pandanus* and a few specimens of *Morinda citrifolia* and *Tournefortia argentea*. The first three are characteristically found under fairly open conditions in a successional stage to forest.

It is convenient to consider the vegetation at the periphery of the island as comprising a shoreline community, reached by the tide and directly exposed to sea winds, and a coastal scrub community immediatelybehind this.

The most common shoreline shrubs at Gan are *Scaevola taccada*, and *Tournefortia argentea*. On the lagoon side, these are frequently covered with the vines of *Canavalia cathartica* and *Vigna marina*. Where the shoreline has been cleared, *Launaea pinnatifida* and *Ipomoea pes-caprae* cover the ground around the hightide line. *Cocos nucifera* occurs at the shoreline near the staging post, and single specimens of *Cordia subcordata* and *Hernandia sonora* on the lagoon shore. Behind the shoreline, *Hibiscus tiliaceus*, *Pandanus* and *Wedelia biflora* characteristically form a dense coastal scrub. This also includes bushes of *Morinda citrifolia*, *Carica papaya*, *Scaevola taccada* and *Tournefortia argentea*, and a variety of herbs, including *Ipomoea pes-caprae*, *Apluda mutica*, *Boerhavia diffusa*. A few specimens of *Pemphis acidula* and a single specimen of *Suriana maritima* were found on the south shore.

Land vegetation of Hitaddu Island

The area occupied by the staging post at Hitaddu is extensively cleared of vegetation. Many of the herbs seen at Gan are also found here, with a few additions, such as *Stachytarpheta indica*.

Immediately surrounding the buildings is an area of open grassland which is completely free of shrubs. *Tridax procumbens* covers the ground extensively, with much *Cassytha filiformis* and patches of *Launaea pinnatifida* and *Apluda mutica*.

North of this area, clearance is not so vigorously maintained, and there is open scrubland. *Apluda mutica* is very common, and a variety of bushes occur; *Scaevola taccada*, *Dodonaea viscosa* occur in the drier areas. The scrub is densest on the seaward side with *Tournefortia argentea*, *Pandanus* juvenile shrubs and tall stands of *Wedelia biflora*. In the centre of the open scrub, much of the ground is open and covered with trailing plants, *Cucumis melo*, *Jacquemontia paniculata*, *Passiflora suberosa*, *Cassytha filiformis* and *Boerhavia diffusa* being common. Other common herbs are *Cleome viscosa*,*Corchorus aestuans*, *Nothosaerva brachiata*. In the extreme northern part of the scrub is a small area of open marshland. At the edge of the water, *Scaevola taccada*, *Morinda citrifolia* and *Muntingia calabura* are typical. Where the water table is at ground level an extensive carpet of *Lippia nodiflora* occurs. Large tussocks of *Cyperus javanicus* form islands, with *Cyperus polystachyos*. *Blumea sinuata* occurs here in shallow water and was not found elsewhere.

Woodland is found to the north and south of the cleared area. To the south, the undergrowth had been cleared beneath the coconuts on the lagoon side, and *Apluda mutica* and *Wedelia biflora* were especially common. To the north, pathways have been cut through the coconuts, and plants such as *Apluda mutica* and *Vernonia cinerea* introduced.

In the midst of the northern forest, parts have been cleared for banana plantation, with a number of original trees such as *Artocarpus altilis*, *Terminalia catappa* and small groves of *Pandanus* left standing. With the opening up of the forest, *Apluda mutica*, *Vernonia cinerea* and *Euphorbia cyathophora* occur as common weeds. *Kalanchoe pinnata* and *Turnera* ulmifolia were common in this area of cultivation, but not seen anywhere else at Gan or Southern Hitaddu.

A transect was taken through the woodland at the northern boundary of the staging post area. Seven zones may be distinguished: (1) on the eastern lagoon side, the soil is dry and under woodland. The main pathway along the island runs along this shore, and there is probably periodic clearing of shrubs. The main trees are Cocos, with Hibiscus tiliaceus and Guettarda speciosa as both trees and shrubs. The herb layer includes Apluda mutica, Launaea pinnatifida, Striga asiatica, and Tacca leontopetaloides. Scaevola taccada is occasionally found on bare ground in clearings.

(2) About 245 metres from the shore, the bush layer becomes much denser, with Guettarda speciosa and Morinda citrifolia more frequent.

(3) About 260 metres from the shore, the ground surface is lower and covered with a mosaic of pools. These are surrounded with bushes of Hibiscus tiliaceus and Guettarda speciosa, and with palm trees separated from each other by distances of 9-12 metres. The ground surface lies 2.4-3 ft. below the crest of the lagoon beach ridge. On the bases of the palm trunks, which are usually surrounded by water, Asplenium pellucidum and Psilotum nudum are found. Moss is also found on the bases of the trunks and in the pools. The pools contain several inches of water, with decaying palm leaves and other debris forming a soft layer a foot or more thick. Two species of sedge grow in the centre of the pools, Fimbristylis sp. projecting 6 inches or more above the surface, and Eleocharis geniculata 2-3 inches. No clearing of vegetation takes place in this marshland, and there is no obvious sign of human interference.

(4) Between 280 and 425 metres from the shore of the lagoon, this marshland vegetation changes into one with Pandanus as the dominant tree, and Cladium jamaicense forming a tall stand below it. The forest is still fairly open. The Pandanus at Hitaddu is of different growth-form from that at Gan. At Gan, mature Pandanus has an erect main stem, with stilt roots leading from the lower part and branches from the upper, to form a fairly compact dense canopy. The Pandanus at Hitaddu in the mature state has thinner, decumbent stems with foliage not in a dense canopy but produced at all levels. At Hitaddu, the Pandanus foliage seems lighter in color and more yellow. Where Cladium jamaicense occurs in a dense stand, no other herbs are seen, and open water is restricted to narrow channels.

(5) At 450 metres from the lagoon shore, the marsh disappears and the ground is covered with dense Pandanus woodland. This was the densest and most impenetrable woodland encountered. It is almost entirely Pandanus, with a little Hibiscus tiliaceus included. The Pandanus trees grow with stems spreading out in groves, and when a certain age is reached a clearing forms in the centre, and Scaevola taccada invades as temporary coloniser. The Pandanus regenerates from the fruit and several seedlings were seen where fruit had fallen to the ground. The ground is covered with a dense mat of dead Pandanus leaves, and there is no herb or shrub layer. There is no evidence of human interference. The small number of species in the mature undisturbed woodland is of interest.

(6) Toward the shore on the seaward side, a dense coastal scrub of *Hibiscus tiliaceus*, *Scaevola taccada*, *Morinda citrifolia*, and *Pandanus* is found. *Scaevola taccada* occurs in woodland clearings and margins, together with *Wedelia biflora* and *Pemphis acidula*. *Terminalia catappa* is also found in this zone.

(7) On the seaward shore itself, *Pemphis acidula* is common all along the crest of the shingle ridge, with *Scaevola taccada* and *Tournefortia argentea* immediately behind. *Scaevola* frequently shows leaf stripping along the shore, and many nearest the sea are dead. *Suriana maritima* is also frequent, particularly in exposed conditions. *Ipomoea pes-caprae* and *Launaea pinnatifida* are not seen on the beach itself, growing only well back from the shoreline, but the grass *Lepturus repens* does occur in these exposed situations and was not seen elsewhere.

In the central part of North Hitaddu there is a large area of open marshland. This appeared from the edge to be largely *Cladium jamaicense*, traversed by frequent channels.

On the lagoon shore at Hitaddu, the vegetation is similar to that at Gan. *Scaevola taccada* is the commonest shoreline shrub together with some *Tournefortia argentea* and *Hibiscus tiliaceus*. To the south, where the island narrows towards Abuhera, both *Pemphis acidula* and *Suriana maritima* are common on the lagoon shore. Behind the shore occurs an open scrubland of *Wedelia biflora*, *Apluda mutica*, *Scaevola*, *Guettarda speciosa*, *Tournefortia argentea* and others.

Coastal scrub on the lagoon side is much less dense than on the seaward--presumably due to the establishment of a major pathway, a few houses and general clearance of vegetation on this side.

Comment: Human activity has thus considerable effects on the vegetation of Gan and Hitaddu. The result of clearing, if only partially, of the mature woodland, is to allow the introduction of many new species, including pantropic weeds, and to increase the number of species per unit area, which probably accounts for the large number of species collected at Gan and Hitaddu. In this connection, comparison with the vegetation of an uncleared Maldivian island would be valuable.

At both Gan and Hitaddu many of the plants are diseased or damaged. This is particularly the case along the shore. Chlorosis was often seen in *Ipomoea pes-caprae* and other herbs. The most serious damage, however, was inflicted on foliage by insects. This is seen in nearly all the shrub and ground-level foliage along the shore, but is especially severe on *Scaevola taccada* and *Ipomoea-pes-caprae*. Grasshoppers particularly occur in vast numbers in the *Ipomoea*. Many trees, shrubs and herbs are also overgrown by creepers, particularly by *Cassytha filiformis*. Several specimens of *Scaevola* are completely smothered by *Cassytha*, with much dead foliage where the *Cassytha* is most abundant.

Marine algae of Gan and Hitaddu Islands

Collection of marine algae at Gan and Hitaddu was carried out either along line or quadrat transects, or by traversing on the reef flats, fixing location with horizontal sextant angles. The latter method was useful in covering large areas rapidly; the transect method gave detailed observations in smaller areas, and was useful in studying zonation. Under difficult conditions no record of precise location was made. The algae were collected in polythene bags, examined fresh, and then transferred to alcohol-formaldehyde preservative, to which metaldehyde had been added as a neutralising agent. Species distribution along transects, Figs. 30-32.

Out of 61 marine species and varieties, 18 were most common in or restricted to the seaward reef, 31 to the lagoon reef, and 15 occurred equally on both. Three species were found only on Hitaddu.

Lagoon reef, Gan

Charts of algal distribution show that for most algae, there was no strict zonation across the reef, but considerable variation along the reef, so that distribution over most of the reef flat was mosaic.

On the basis of algal distribution, it was possible to divide the lagoon reef from the shore to the base of the reef slope, into three major zones. Distance on the lagoon reef were measured from a sand ridge which was presumably high tide line.

(1) An inshore zone (20-60 ft). Algae found here were specific to this zone, characterised by a loose sand substratum, continuous water motion, and high turbidity. Chaetomorpha brachygona, C. crassa and Enteromorpha sp. occurred very close inshore, attached to stones and pieces of coral lying in the sand. Just beyond this, Padina commersonii formed a very characteristic zone.

(2) An inshore zone (60-150 ft) between the zone of turbulence and the beginning of the large dead coral masses. The substrate was mainly sand patches with much dead coral litter.

Beyond the Padina zone, Dictyota sp. and Jania capillacea covered the ground in large patches. Intergrading with, and beyond this, Halimeda incrassata was common on sand and coral fragments. Halimeda discoidea and Boergenesia forskii were also common in this zone along parts of the reef. Caulerpa lentillifera and C. racemosa var. macrophysa were especially luxuriant here.

(3) From about 150 ft to bottom of the reef slope. The whole of this zone is characterised by an abundance of dead and living corals. Both the completely dead corals, and the dead parts of living ones were covered by epiphytic algae. The epiphytic habit was thus the predominating one in this part of the reef.

Common epiphytic algae included Hypnea sp., Jania capillacea and Lophosiphonia villum which formed a mat-like covering over the coral. Lyngbya majuscula occurred as a mass of threads attached to the coral. Most of the algae seen in zone 3 on the reef flat also occurred on the reef slope, e.g. *Dictyota* sp., *Caulerpa lentillifera*, *Gelidium divaricatum*. Exceptions to this were few, and included *Lyngbya majuscula* and *Polysiphonia ferrulacea* which were rare on the reef slope, and *Symploca hydnoides* and *Pocockiella variegata* which were common on the reef slope but not on the flat. *Pocockiella* was a very common epiphyte on dead coral on the reef slope and represented the most significant difference between it and the reef flat.

Seaward reef, Gan

The seaward reef profile was divided into two major areas, separated by the rubble or boulder zone.

(1) Shore-boulder zone, a shallow zone of little water movement and exposed to sun and rain. Algae were not plentiful in this zone. Much of the reef was covered by *Thalassia* and *Cymodocea*, with patches of sand and marine grass forming a mosaic. *Cladophora* sp. was common over the whole of the reef as free floating or loosely attached to the marine grass. *Jania capillacea* and *Boergenesia forskii* were common in the sand between and within patches of marine grass.

(2) Boulder zone to surge channels. Between the boulder zone and the surge channels there were 3 main zones:

a. In the region of the surge channels, towards the edge of the reef, the coral rock was almost entirely covered by encrusting red algae.

b. At the ends of the surge channels, and for a distance up to 30 ft, the growth of algae was luxuriant. A few algae were restricted to this zone, *Caulerpa racemosa* var. *peltata*, *Codium arabicum* and *Valonia utricularis*. Algae which were particularly common included *Codium edule*, *Halimeda opuntia* and *Jania capillacea* which formed compact bunches, with strong attachment to the coral rock. *Pocockiella variegata* was luxuriant on rock surfaces between algal clumps.

c. Between zone b and the boulder zone, algal growth was not so luxuriant. This was a zone of algal pavement with clumps of *Halimeda opuntia*, *H. discoidea* and *Jania capillacea* distributed over it. *Turbinaria ornata* occurred towards the sea end, as small rosettes covering much of the ground. *Pocockiella variegata*, *Schizothrix calcicola* and *Cladophoropsis* sp. occurred on rock surfaces.

Seaward reef, Hitaddu

The seaward reef at Hitaddu was narrow compared with Gan, a width of about 250 yards as against 900, distances measured to beginning of surge channels. The physical appearance of the reef is very like the outer part of the seaward reef at Gan, consisting over nearly the whole surface of hard coral pavement, with a boulder ridge on the shore in places. The transect taken across the reef at Hitaddu was divisible into 2 distinct algal regions:

(1) An outer zone, about 60 ft offshore to the surge channels. The number of algae was large over the whole of this zone comparable with the outer reef zone at Gan. The force of wave action seemed less at the edge of the reef at Hitaddu than at Gan, and there was no zone of marked algal abundance as at Gan close to the surge channels.

The algae over the whole zone were comparable to those seen at Gan, *Caulerpa racemosa* var. *peltata* and *Valonia utricularis* occurred in the outer zone. *Halimeda opuntia*, *H. discoidea*, *Jania capillacea*, *Pocockiella* variegata, Turbinaria ornata, Boodlea composita, Cladophoropsis sp., and Dictyosphaeria intermedia var. intermedia were recorded as occurring over most of the reef. Neomeris mucosa occurred mid-reef at Hitaddu, and was only seen elsewhere in strong current on the far seaward side of the Gan-Fedu gap.

(2) An inshore zone within about 60 ft from the shore. This was a zone of continual water motion, and was closely similar to the inshore zone at Gan lagoon reef. Two algae were recorded, Padina commersonii forming a distinct zone, and inshore to this, Chaetomorpha gracilis growing on stones and loose coral rock.

Notes on occurrence of algae collected[*/]

Myxophyceae

Anacystis montana

Gan, seaward reef. Covered the surface of low lying beachrock in the Gan-Fedu gap. Periodically submerged and exposed by the tide.

Calothrix pilosa

Gan, seaward reef. Found in association with A. montana on beach rock.

Hormothamnion enteromorphoides

Gan, lagoon reef: found in inshore zone, within 100 ft from shore. Seaward reef: fairly common over most of the reef flat between the shore and the boulder ridge, appearing as a brown-golden covering on stones and dead coral.

Lyngbya aestuarii

Appeared as a greenish felt of projecting filaments on dead coral. Gan, lagoon reef: fairly rare on dead coral from about 100 ft to the reef edge.

Lyngbya majuscula

Gan, lagoon reef: common, especially from about 100 ft to reef edge. Uncommon in the inshore zone, and a few specimens were found on the reef slope. Seaward reef: quite rare between the shore and boulder ridge, becoming slightly more frequent between the ridge and the surge channels.

Schizothrix calcicola

Gan, seaward reef: very common as a covering on stones and rocks, between the shore and boulder zone.

Symploca hydnoides

Wide variation in external appearance, collected as 7 different forms. Gan, lagoon reef: uncommon over the whole of the reef flat, but becoming fairly common near the reef edge, and common on the reef slope. Seaward reef: uncommon, occurring in the shoreward half of the reef flat, between shore and boulder zone.

[*/] The data on occurrence were received too late to be of use to the algologists who identified the collection, and even to be incorporated in their systematic list below (Tsuda and Newhouse, Chapter IV, Part D). Their identifications, however, are utilized in the present enumeration, but see last paragraph on p. 93 [ARB Eds.]

Chlorophyceae

Boergesenia forbesii
Gan, lagoon reef: occurring at the western end of the island, on the reef between about 100-150 ft from shore, where it was common on a substratum of sand and dead coral fragments. Seaward reef: seen over a wide area of reef flat, between shore and boulder zone, where it was locally common. It was not common between the boulder zone and surge channels.

Boodlea composita
Gan, lagoon reef: common and restricted to outer zone of the reef, from about 200 ft to the reef edge. Seaward reef: not common, occurring between the boulder zone and the surge channels.

Boodlea sp.
Gan, lagoon reef. A few specimens were found on the reef slope, at a depth of about 60 ft.

Bryopsis pennata
Gan, lagoon reef: common in mid-reef zone, between 100-200 ft, found occasionally over most parts of the reef. Seaward reef: generally uncommon, occurring occasionally over the greater part of the reef.

Caulerpa lentillifera
Gan, lagoon reef, western end. Common in the middle of the reef, from 100-200 ft, uncommon on the lagoon edge and on the reef slope.

C. racemosa var. *macrophysa*
Habitat closely similar to that of *C. lentillifera*.

C. racemosa var. *peltata*
Gan, lagoon reef: uncommon, occurring locally in the mid-reef zone, 100-200 ft from shore, with a few specimens occurring either side of this. Seaward reef: uncommon, between the boulder ridge and the surge channels. Hitaddu, seaward reef: not common, occurring toward the seaward edge of the reef.

C. serrulata var. *typica*
Gan, Gan-Fedu Gap: common and restricted to this area, on the seaward side between islands. Occurred on sand substratum, as small colonies, with a distinctly yellowish appearance.

C. taxifolia
Gan, lagoon reef: uncommon, occurring at the western end of the island, 40 to 250 ft from shore.

Chaetomorpha brachygona
Gan, lagoon reef: uncommon, occurring locally along the reef. A filamentous green alga living on dead coral fragments, it occurred close inshore, 20-50 ft from high tide line.

C. crassa
Gan, lagoon reef: uncommon, restricted to a zone 20-100 ft from shore.

C. gracilis
Hitaddu, seaward reef: common and restricted to close inshore zone, 0-20 ft from tideline.

Cladophora sp.

Gan, lagoon reef: uncommon, attached to rocks and dead coral, occurring between 20-250 ft from shore. Seaward reef: common between shore and boulder zone.

Cladophora sp.

Gan, lagoon reef: uncommon, attached to stones and coral, inshore zone 20-250 ft.

Cladophoropsis sp.

Gan, seaward reef: uncommon, occurring between the boulder ridge and the surge channels, where it was attached to coral pavement and loose rocks. Hitaddu: common over the whole of the seaward reef from 60 ft to edge.

Codium arabicum

Gan, seaward reef: not common, but found several times in the dense algal growth near to the surge channels.

C. edule

Gan, lagoon reef: a few specimens only were found in one locality, attached to dead coral about 250 ft from shoreline. Seaward reef: fairly common, between the boulder zone and the surge channels, attached to the underside of rocks near the boulder zone and to the surface and cavities of the porous rock at the surge channels.

Dictyosphaeria intermedia var. intermedia

Gan, seaward reef: occurring only very occasionally between shore and boulder zone, but fairly common between boulder zone and surge channels. Hitaddu, seaward reef: fairly common over a wide area of reef from about 50 ft from shore to the reef edge.

Enteromorpha sp.

Gan, lagoon reef: strictly an inshore alga on the reef flat, where it occurred 20-50 ft from high tide line. It was attached to stones and dead coral lying loose in the sand. A few specimens were also found on the reef slope on dead coral at about 50 ft depth.

Halimeda discoidea

Gan, lagoon reef: uncommon, locally common along the reef. It occurred between 50 and 200 ft from shore, attached to sand or loose lying rocks. Seaward reef: common in the boulder zone to surge channels. Hitaddu, seaward reef: quite common within 130 ft from the surge channels at the edge of the reef.

H. incrassata

Gan, lagoon reef: common inshore, the inner limit being fairly sharp at 60 ft from high tide line, the range extending lagoonwards to about 150 ft;beyond this the alga was uncommon. Seaward reef: found occasionally attached to rubble and coral pavement in the boulder zone and up to halfway between this and the surge channels. A few specimens were also found between the shore and the boulder zone.

Halimeda opuntia

Gan, lagoon reef: as with H. incrassata, common between 60 and 150 ft from shore. Seaward reef: very common between the boulder zone and the surge channels. It was the species of Halimeda extending farthest seaward, almost up to the channels, where it had a very compact growth form. Hitaddu, seaward reef: fairly common in the mid part of the reef.

Neomeris mucosa

This had the appearance of small bunches of bright green fingers, and occurred in conditions of good water flow. Gan, seaward reef: uncommon, between boulder zone and surge channels, and found only at the Gan-Fedu Gap. Hitaddu, seaward reef: a few specimens were found in the mid part of the reef, attached to the coral pavement.

Tydemania expeditionis

Gan, lagoon reef: very characteristic of the outer reef zone, 200 ft to edge, where it was sparsely distributed. Common also on the reef slope to depths of 60 ft. A few specimens were attached to coral brought up from a knoll in the lagoon, depth 30 ft.

Udotea orientalis

Gan, lagoon reef: occurrence very sporadic, specimens were collected from inshore, mid reef and outer reef. Seaward reef: a single specimen was collected during traverses between the shore and the boulder zone. The species was quite common between the boulder zone and surge channels opposite the Gan-Fedu Gap. Hitaddu, seaward reef: fairly common in the middle part of the reef.

Valonia utricularis

Occurred as a dense mat of green vesicles, well attached to the rocky substratum. Gan, seaward reef: uncommon, between the boulder ridge and the surge channels. Hitaddu, seaward reef: common at the edge of the reef, within 150 ft of the surge channels.

V. ventricosa

Solitary, olive green vesicles, concealed within coral masses, or in crevices in rocks. Gan, lagoon reef: fairly common on reef slope, to depth of about 30 ft, less common over most of the reef flat. Seaward reef: a few specimens were found in the porous coral near the surge channels.

Phaeophyceae

Dictyota friabilis

Gan, lagoon reef: not common, found mainly on the inshore part of the reef in patches at about 40-60 ft.

Dictyota sp.

Gan, lagoon reef: common over the whole of the reef. Especially common in an inshore zone at about 50-150 ft, where it formed a carpet on the sand. Common in other parts of the reef on dead coral, occurring on the reef slope to a depth of 70 ft. Seaward reef: uncommon on the reef flat between shore and boulder zone, common between boulder zone and surge channels. Hitaddu, seaward reef: common over the whole of the reef except the inshore 50 ft, and the surge channel zone.

Hydroclathrus clathratus

Gan, seaward reef: not common, seen on the coral pavement midway between the boulder zone and the surge channels, and in the boulder zone itself. Gan-Fedu Gap: quite common in the sand on the seaward side of the channel between the two islands.

Padina commersonii

Gan, lagoon reef: very characteristic as an inshore alga, between 30 and 50 ft from shore. Gan, seaward reef: rare, a few specimens were found between the shore and the boulder ridge. Hitaddu, seaward reef: very characteristic inshore plant, occurring within 60 ft of the shore.

Pocockiella variegata

Gan, lagoon reef: common on the reef slope, where it formed a common covering over dead coral to a depth of 70 ft. Uncommon on the reef flat, occurring as occasional specimens. Seaward reef: abundant covering on rocks and coral pavement between the boulder zone and the surge channels. Hitaddu, seaward reef: abundant over most of the outer zone of the reef, especially so within 100 ft of the surge channels.

Sphaceleria sp.

Gan, lagoon reef: uncommon in the mid part of the reef.

Turbinaria ornata

Gan, lagoon reef: occurred very infrequently in the middle of the reef flat, attached to coral. Seaward reef: common between the boulder ridge and the surge channels, as small, rosette-like plants attached to the coral pavement. It occurred between the shore and the boulder zone as an occasional find, and was of moderate size (3 inches long). In the area shore to boulder zone at the eastern end of Gan, the Turbinaria was of large size, and attached to coral microatolls in the swiftly flowing current. Gan-Fedu Gap: large well developed specimens attached to microatolls in the strong current. Hitaddu, seaward reef: abundant over the whole of the reef flat except the close inshore zone, as small compact rosettes.

Rhodophyceae

Antithamnion sp.

Gan, an epiphytic pink alga, occurring on Caulerpa and associated algae and on dead coral. Lagoon reef: fairly common on the reef flat in the mid and outer zones of the reef.

Botrycladia skottsbergii

Gan, lagoon reef: generally uncommon over the reef flat, most frequent in the mid zone of the reef, occurring on the underside of dead coral rock. Seaward reef: a few specimens were found in cavities in the porous coral rock in the surge channel region.

Ceramium fimbriatum

Hitaddu, seaward reef: restricted to the close inshore zone (0-60 ft), where it was common.

Ceratodictyon spongiosum

Gan-Fedu Gap: occurred as a spongy, olive brown thallus on the seaward side of the gap, on a sand substratum.

Champia parvula
Gan, lagoon reef: fairly common in close inshore zone, on sand.

C. salicornoides
Habitat closely similar to that of C. parvula

Dasya sp.
Hitaddu, seaward reef: common in the mid region of the reef, attached to the coral pavement and to coral rocks.

Dictyurus purpurescens
Gan, lagoon reef: a pink alga, which occurred only in the mid region of the reef flat as a few specimens along one of the transects (200-250 ft from shore).

Galaxaura marginata
Gan, a massive pink alga. Lagoon reef: rare, only a few specimens found, attached to coral heads in the mid-outer region of the reef flat.

G. rudis
Gan, lagoon reef: not common, occurring locally along the reef; most frequent in the mid reef zone; specimens also found inshore, and on the reef slope.

Gelidium divaricatum
Gan, lagoon reef: occurred on the surface of stones, dead coral and living Halimeda. Occasional over the whole of the reef flat, and on the reef slope to a depth of 40 ft. Seaward reef: single specimen seen near reef edge. Lagoon knoll: specimens brought up on dead coral from surface of knoll, 30 ft below surface.

Griffithsia sp.
Gan, lagoon reef: rare, occurring from about 250 ft to edge.

Herposiphonia sp.
Commonly occurred as an epiphyte on Halimeda. Gan, lagoon reef: uncommon, occurring mid reef at 200-270 ft, also infrequently found on reef slope, depth 30 ft. Hitaddu, seaward reef: a few specimens occurred at mid reef.

Hypnea sp.
Gan, seaward reef: rare, occurring between boulder zone and reef edge. Another form occurred as thick brown filaments twining through cavities in the coral rock. Gan, seaward reef: fairly common near the surge channels, uncommon between boulder zone and shore. Hitaddu, seaward reef: common over middle part of reef. Gan, lagoon reef: another form common on dead coral, 40 to 250 ft from shore. Seaward reef: common between shore-boulder zone. Gan, lagoon reef: still another form common on dead coral from 80 ft to reef edge, and on upper part of reef slope (to depth 40 ft).

Jania capillacea

This was the most common alga observed at Addu atoll in marine habitats. Gan, lagoon reef: common over the whole reef flat except the close inshore zone, from 40 ft to near the bottom of the reef slope at 80 ft depth. It was especially common in the midreef zone, where it formed clumps on the sand and rock substrate, and was also common attached to dead coral. Seaward reef: locally common between the shore and the boulder zone, having a patchlike distribution over the whole area. Abundant between the boulder zone and the surge channels, occurring near the channels as especially compact masses with high calcification. Hitaddu, seaward reef: common over the whole of the reef except the inshore 150 ft, occurring in masses on the coral pavement.

Lophosiphonia villum

Occurred as a reddish, velvet-like covering on stones and dead coral. Gan, lagoon reef: common on dead coral in the midreef zone, between 150 to 300 ft, less common to the reef edge, and rare on the reef slope. Gan, seaward reef: rare, a few specimens were found near the surge channels. Hitaddu, seaward reef: rare, a few specimens about 30 ft offshore. Lagoon knoll: fairly common on dead coral brought up from the summit of the knoll, depth 30 ft.

Polysiphonia ferrulacea

Gan, lagoon reef: common on outer part of reef, from 140 ft to reef edge, where it occurred on sand and rock substratum. Seaward reef: rare, between shore and boulder ridge. Gan-Fedu Gap: common, on sand, midway between islands.

Spyridea filamentosa

Gan, seaward reef: occurred as a mass of pinkish filaments, close to the shore at the eastern end. Very local.

Tolypiocladia glomerulata

Gan, lagoon reef: quite common, and local, at the western end of the island, forming dark red clumps on dead coral masses. Most frequent from 100 to 200 ft from shore.

Viadlia serrata

Gan, lagoon reef: locally fairly common, 150 to 200 ft from shore.

Freshwater and terrestrial algae

Nostoc commune

Gan, locally common on open waste ground with grassland, where the water table was high. Formed olive green masses, which under wet conditions, as just after a rain shower, became swollen and apparent.

Pithophora oedogonia

Gan, found floating on the surface of fresh water in an old well at the centre of the island.

ACKNOWLEDGMENT: I am very grateful to Mr. R. Tsuda and Mr. J. Newhouse for undertaking the identification of the collection. Also to Dr. D.R.Stoddart as leader of the expedition, and to Dr. P. Spencer Davies and Mr. A. Keith for collecting specimens from the reef slope and the lagoon knoll.

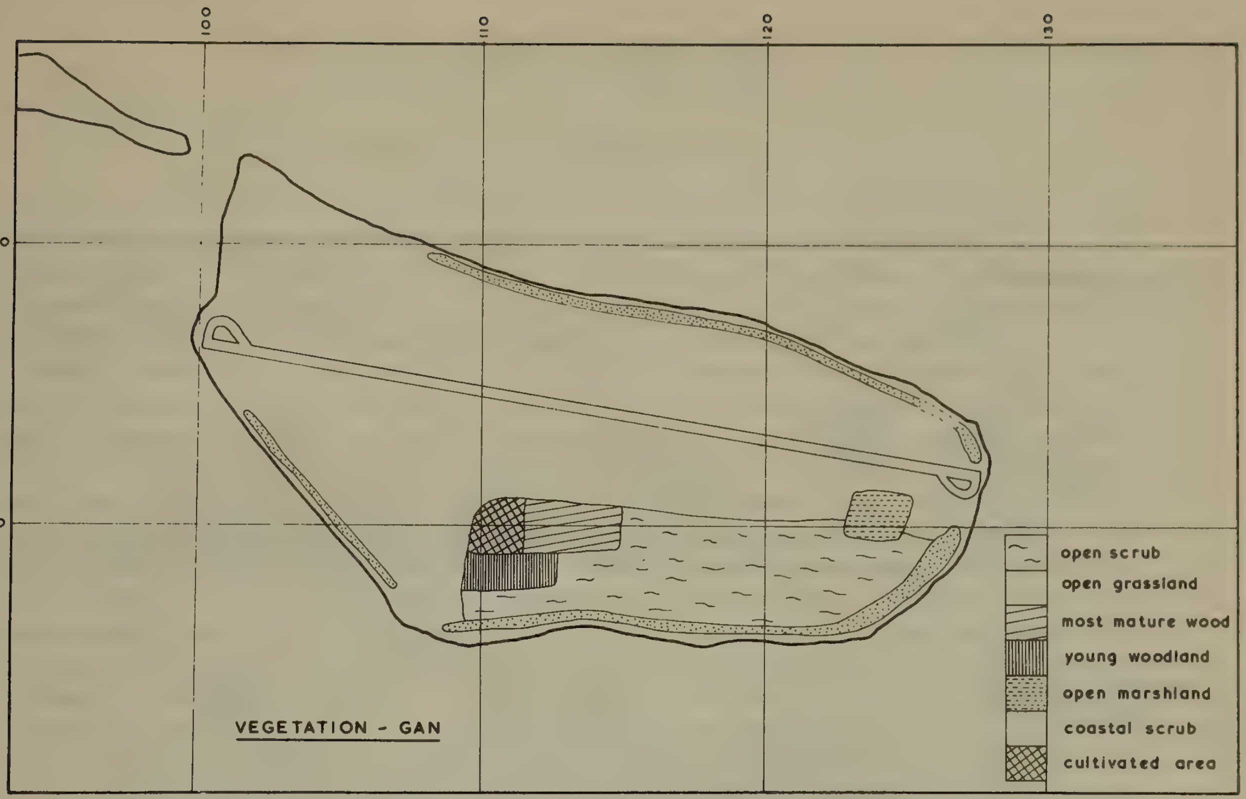
100
110
120
130
140
150
VEGETATION - GAN
open scrub
open grassland
most mature wood
young woodland
open marshland
coastal scrub
cultivated area

Fig. 29. Vegetation of Gan Island, 1964.

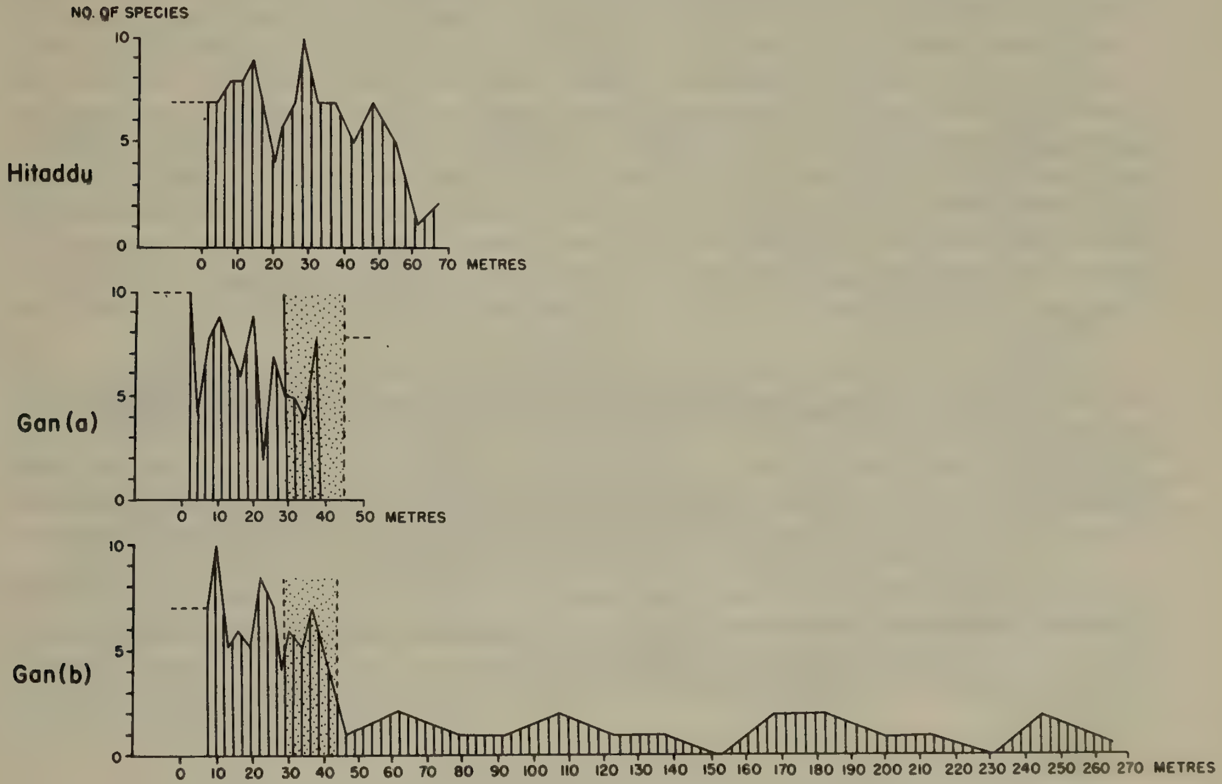

Fig. 30. Distribution of number of algal species collected in 10 ft quadrats on the seaward reef flat in transects at Hitaddu and Gan Islands. Transect Gan (a) is incomplete.

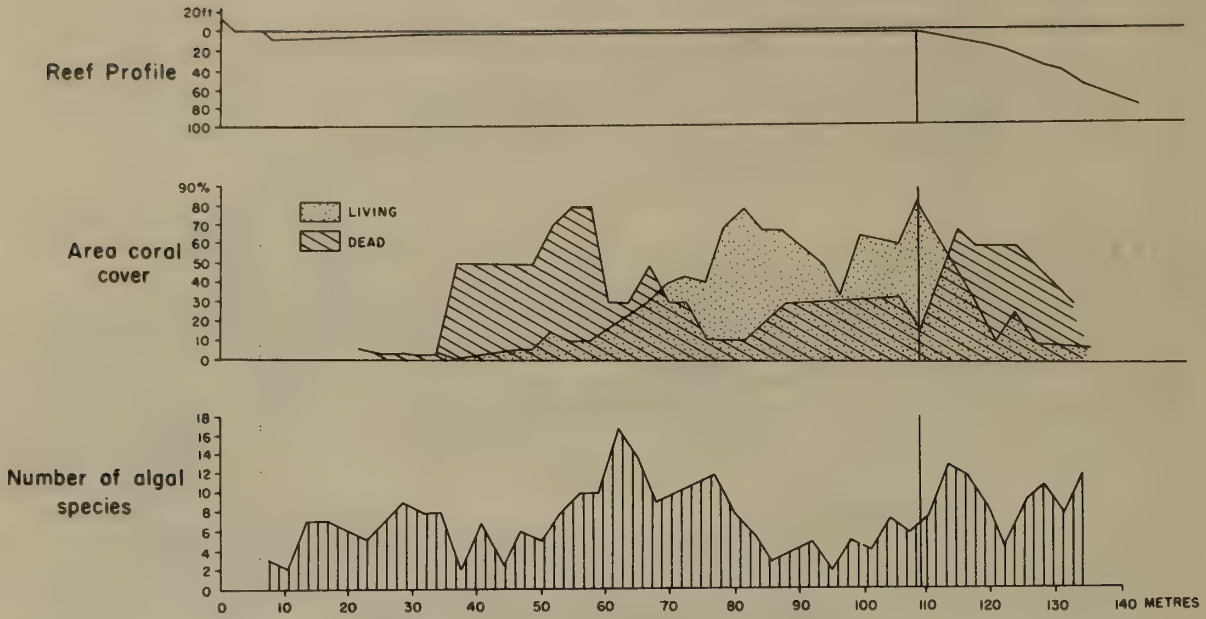

Fig. 31. Distribution of number of algal species and percentage coral cover in Gan lagoon reef transect I, based on 10 ft quadrats.

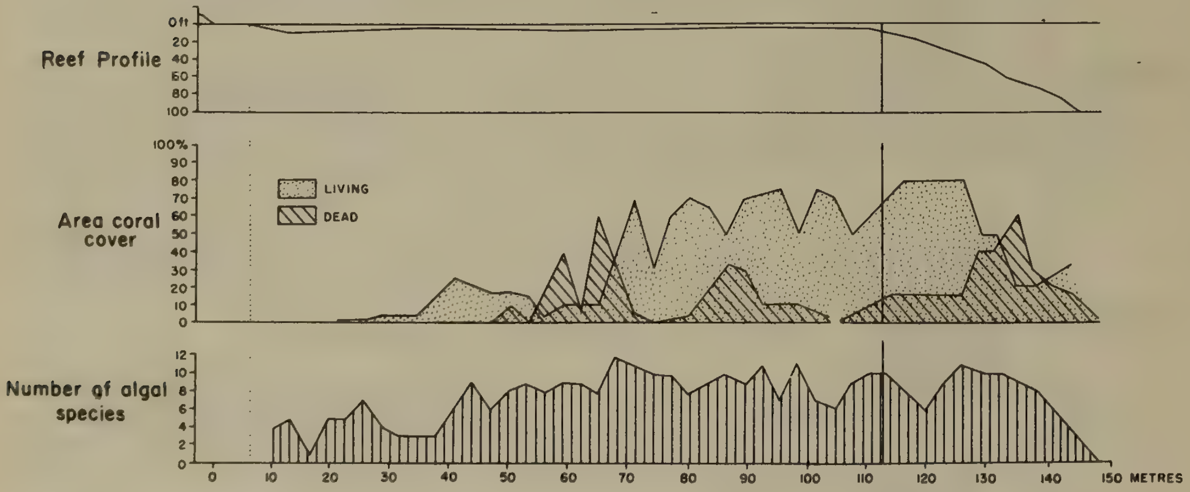

Fig. 32. Distribution of number of algal species and percentage coral cover in Gan lagoon reef transect II, based on 10 ft quadrats.

C. List of Addu vascular plants

by F. R. Fosberg, E. W. Groves and D. C. Sigee

The vascular plants collected by Mr. Sigee were independently identified by Fosberg and Groves, and the resulting lists combined and the differences reconciled. 145 specimens, in all, were collected, representing 142 species. Of these 57 (marked with an asterisk *) were clearly exotic, 33 of them cultivated or immediately persisting from cultivation; 32 are widespread maritime species. Most of the remainder are widespread species that occur in tropical Asia, some pan-tropical. Some of them may well be indigenous, but this is difficult to be certain of, one way or the other. There are no local endemics, unless the *Euphorbia* sp. should turn out to be one, and it seems likely that it is an Indian species that has been commonly, but erroneously, regarded as a variety of *E. hypericifolia*. Further study of more ample material may determine this. The *Pandanus* sp. (sterile) may well belong to one of the local populations that have been regarded as species in this perplexing genus. The *Fimbristylis* sp. may possibly be new and local, but is more likely an extreme or variant form of a known species.

This collection illustrates very well the state of our knowledge of the floras of the islands that are a little off the beaten track. In the 145 specimens, representing 142 species, there are 40 newly recorded from the Maldive Archipelago. 105 species are clear new records from Addu. 23 more are possibly new records, as they are plants mentioned by Willis and Gardiner (Ann. R. Bot. Gard. Peradeniya 1(2): 45-164, 1901) as occurring generally throughout the group, but not specifically mentioned by them from Addu. This is a large proportion of new records, found in spite of (in certain cases possibly because of) the almost total destruction of the natural and planted vegetation by the construction of an air base. It seems clear that a great deal of careful collecting still must be done before we can claim anything like an adequate picture of the floras of the world's islands.

In addition to the bare records of species collected, Sigee's notes on their occurrence on the three islets visited have been added. The observations placed *after* the citation of the collection number do not necessarily apply strictly to the local population from which the specimen was collected. The notes *before* the citation presumably apply to the plant actually collected.

Since the list of Maldive plants was published (ARB 58) in 1957, there have been certain changes in our understanding of some of the species included in it, and certain changes in nomenclature. A list of these has been added at the end of this paper, whether or not they apply to Addu species.

PDERIDOPHYTA

Psilotaceae

Psilotum nudum (L.) Beauv.

Hitaddu islet, in water, in forest area north of staging post, in closed forest where water table was at ground level, Sigee 90.

Polypodiaceae

Asplenium pellucidum Lam.?

Hitaddu islet, common in northern forest area, on tree stumps, around open pools, Sigee 105. New record for the Maldives.

Nephrolepis hirsutula (Forst. f.) Presl

(Possibly the plant recorded as N. exaltata (L.) Schott by Willis & Gardiner; see ARB 58).

Gan islet, abundant, forming dense stands in the dense central woodland, Sigee 57. Also found in regenerating woodland nearby; on Hitaddu I., found only in the northern forest area, associated with Psilotum and Asplenium.

Thelypteris goggilodus (Schkuhr) Small

Gan islet, in open woodland with high water table, Sigee 41. Very common in open scrubland at the S.E. end. Fairly common also in central dense woodland, S.E. marshland and roadsides. New record for the Maldives.

SPERMATOPHYTA

Cupressaceae

*Juniperus sp. ?

Gan islet, Sigee 0. Recent introduction, cultivated bush along roadsides near RAF buildings. New record for the Maldives.

*Thuya orientalis L.

Gan islet, in village near Officers' Mess, Sigee P. Recent introduction, cultivated to form low sparse hedge. New record for the Maldives.

Pandanaceae

Pandanus sp.

Gan islet, common in coastal scrub along margin of island, Sigee 76. Some trees also in the central dense woodland, in open scrub, and a few juvenile plants in the S.E. marshland. On Hitaddu islet, abundant in coastal scrub on seaward side of island, also in seaward half of northern forest area. Juvenile specimens occurred infrequently in staging post area.

Potamogetonaceae

Cymodocea ciliata (Forsk.) Asch.

Gan islet, on submerged reef, between shore and boulder edge of reef, Sigee 25. On lagoon and seaward reef flats on both Gan and Hitaddu islets. Common and widespread on seaward flat, occurring in conditions of continuous, moderate water flow; localized on the lagoon reef to an inshore zone. New record for the Maldives.

Hydrocharitaceae

Thalassia hemprichii (Ehrenb.) Asch.
Gan islet, between boulder ridge and reef edge, Sigee 26. On lagoon and seaward reef flats of both Gan and Hitaddu islets. Distribution generally similar to Cymodocea. New record for the Maldives.

Gramineae

Aeluropus littoralis (Gouan) Parl.
Hitaddu islet, lagoon side, sand-coloniser, Sigee 93. Seen only along lagoon shore, on beach, where it was fairly common. New record for the Maldives.

Apluda mutica L.
(A. varia var. aristata L.)
Gan islet, on top of sand bank 20 yards from sea, with Ipomoea and on bare sand, Sigee 13. Abundant on both islets (Hitaddu and Gan), where there has been a clearance of vegetation. Common throughout Gan, except in the central dense woodland area and in the grassland surrounding the runway. On Hitaddu islet, abundant in the staging post scrub, and common on the lagoon side of the forest north and south of this.

Bambusa multiplex (Lour.) Rausch ?
Gan islet, in gardens, Sigee X. Recent introduction.

Cenchrus echinatus L.
Gan islet, near huts, Sigee 82. Uncommon in open grassland in the immediate vicinity of RAF buildings. New record for the Maldives.

Chrysopogon aciculatus (Retz.) Trin.
Gan islet, in grass wasteland, near buildings, Sigee 80. Common in open grassland, also occurring along roadsides. New record for Maldives.

*Dactyloctenium aegyptium (L.) Willd.
Gan islet, in wasteland near buildings, Sigee 81. Common in open grassland and along roadsides. Hitaddu islet, common in staging post area. New record for the Maldives.

Digitaria timorensis (Kunth) Balansa
Gan islet, common in the open grassland and along roadsides, Sigee 62. New record for the Maldives.

*Eleusine indica (L.) Gaertn.
Gan islet, east end, lagoon side, in wasteland, in shade, in patches on bare ground, Sigee 19. Common in the open grassland and along roadsides. Hitaddu islet, in staging post area.

*_Eragrostis tenella_ (L.) Beauv.
(_E. amabilis_ (L.) W. & A.)
Gan islet, near east end, lagoon side, in wasteland, _Sigee 18_.

Lepturus repens (Forst. f.) R. Br.
Hitaddu islet, coloniser, on seaward shore, _Sigee 91_. New record for the Maldives.

Panicum repens L.
Gan islet, _Sigee 64_. New record for the Maldives.

Paspalum commersonii Lam.
Gan islet, fairly common in open marshland at S.E. end, _Sigee 89_. New record for the Maldives.

*_Sorghum bicolor_ (L.) Moench
Gan islet, sporadic in open grassland at N.W. end of airstrip, _Sigee 74_.

Thuarea involuta (Forst. f.) R. & S.
Gan islet, eastern tip, shoreline, in open, near sea, covering ground with Cassytha, _Sigee 27_; also common in open grassland at N.W. end, surrounding runway and along roadsides. Hitaddu islet, common in staging post area.

Cyperaceae

Cladium jamaicense Crantz var. _chinense_ (Nees) Koyama
Hitaddu islet, in marshland, by side of open water, _Sigee 97_. Locally common in marshland of northern forest, and also observed covering a wide area of open marshland north of the staging post area, in the midst of the forest. On Gan islet, seen only in small amounts in the S.E. marshland.

Cyperus brevifolius (Rottb.) Hassk.?
Gan islet, single colony found in open scrub at S.E. end, forming lush stand on wet ground, _Sigee 84_. New record for the Maldives.

Cyperus conglomeratus Rottb. f. _pachyrrhizus_ (Nees) Kük.
Hitaddu islet, only a few colonies observed, lagoon shore, just south of staging post area, _Sigee 102_.

Cyperus javanicus Houtt.
Gan islet, common in the S.E. open marsh area, and scrubland, _Sigee 24_. On Hitaddu islet, fairly common in the staging post area.

*_Cyperus ligularis_ L.
Gan islet, grassland, _Sigee 4_; common in the S.E. marsh area. On Hitaddu islet, common in staging post area. New record for the Maldives.

Cyperus melanosperma (Nees) Sur.
Gan islet, near airstrip, grassland, _Sigee 66_. Uncommon in the open grassland and roadsides, where the ground has had free surface water. New record for the Maldives.

Cyperus polystachyos Rottb.

Gan islet, east end, south of runway, in marshland (high water table), *Sigee 38*. Common in the wetter zones of the open grassland surrounding the runway, and in the S.E. marshland. On Hitaddu islet, fairly common in staging post area, in the marshland adjacent to the northern boundary.

**Cyperus rotundus* L.

(But spikelets very pale)

Gan islet, behind oil tanks, in grassland, dense forest, *Sigee 17*. Common in S.E. marshland, open grassland, and along roadside. On Hitaddu islet, fairly common in staging post area.

Eleocharis geniculata R. and S.

Hitaddu islet, northern forest, in open pools, just projecting above water surface, in open woodland area, *Sigee 106*. New record for the Maldives.

Fimbristylis cymosa ssp. *spathacea* (Roth) Koyama

(A slender form with unusually small spikelets)

Gan islet, *Sigee 40*. Common in S.E. marsh area, uncommon in scrub and along roadsides.

Fimbristylis sp.

Gan islet, in marshland, *Sigee 39*. Common in southern marsh area. On Hitaddu islet, seen only in the northern forest area, where it was localized in open pools.

Araceae

**Colocasia esculenta* (L.) Schott

Gan islet, center, in dense fern stand, *Sigee 59*. Mature plants occurred in the gardens, where they were obviously cultivated. A few mature specimens were also seen in the scrub in the centre of the island, and juvenile forms occurred in clearings in the central woodland.

Palmae

Cocos nucifera L.

Gan islet, common around RAF buildings, and along the lagoon shore at the northwest tip of the island. Hitaddu islet, common in the forest north and south of the staging post. The lagoon side of the forest comprised open coconut woodland. Not collected.

Commelinaceae

Cyanotis axillaris (L.) D. Don

Gan islet, center, in open fern land, *Sigee 78*. Seen only at edge of clearings in central woodland. New record for the Maldives, first found there by Groves in 1943-45.

Cyanotis cristata (L.) D. Don

Hitaddu islet, north part, in clearing, *Sigee 113*. A single colony was seen in a dense area of the northern forest in a clearing near an old native dwelling.

Liliaceae

**Gloriosa superba* L.

Gan islet, southern side, in bush scrub, *Sigee 53*. Uncommon, found in open scrubland in the centre of the island adjacent to the woodland.

Amaryllidaceae

Crinum asiaticum L.

Gan islet, in gardens, *Sigee AD*. Hitaddu islet, planted in rows by the wayside adjacent to the RAF buildings, *Sigee L*, south side in clearing, *Sigee 101*. The Hitaddu specimens are leaves only, so the determination is uncertain.

**Zephyranthes rosea* Lindl.

Hitaddu islet, *Sigee K*. Planted as ornamental along roadsides near RAF buildings.

Taccaceae

Tacca leontopetaloides (L.) O. Ktze.

Hitaddu islet, in clearings in woodland, *Sigee 96*. Occurrs in the northern forest on the lagoon side, where conditions are fairly open.

Musaceae

**Musa* sp.

Hitaddu islet, seen only in banana plantation north of trading post area. Gan islet, small plantation seen near the Pakistani village, just south of the runway. Not collected.

Casuarinaceae

Casuarina equisetifolia L.

Gan islet, single tree in village near Officers' Mess, *Sigee Q*.

Moraceae

**Artocarpus altilis* (Park.) Fosb.

Gan islet, *Sigee 60*. A few trees were left standing near the RAF buildings. Hitaddu islet, a few specimens seen in the banana plantation north of the staging post.

Urticaceae

Pouzolzia indica Gaud.

Hitaddu islet, north, in clearing, *Sigee 114*. Gan islet, a few specimens seen on a bank in the southeast scrub.

Nyctaginaceae

Boerhavia diffusa L. ?

Gan islet, east end of island, *Sigee 46*. A few specimens were seen near the RAF buildings, and in the scrub at the southeast end. Hitaddu islet, commonly found in the staging post area, where it spreads across open ground.

*X *Bougainvillea buttiana* Holttum & Standley

(Perhaps the plant recorded as *B. spectabilis* Willd. in ARB 58)

Gan islet, in hedgerow, *Sigee I*. Recent introduction, cultivated near the RAF buildings.

**Bougainvillea glabra* Choisy

Gan islet, *Sigee J*. Recent introduction, cultivated near RAF buildings.

Amaranthaceae

Alternanthera sessilis (L.) R. Br.

Gan islet, center, in scrub on rough ground, *Sigee 73*. Not common, typically found at the edge of the grass verge near to the road. New record for the Maldives.

**Celosia argentea* L.

Gan islet, behind oil tanks, on grassy wasteland, *Sigee 16*. Widely scattered over the open grassland surrounding the runway, and in the scrub.

Nothosaerva brachiata (L.) Wight

Gan islet, roadside rubble, *Sigee 75*. Common in scrub, by roadsides and near buildings. Hitaddu islet, infrequently found in the staging post area.

Portulacaceae

**Portulaca oleracea* L.

Gan islet, near oil drums, on bare waste ground, *Sigee 42*. Uncommon in open grassland. Hitaddu islet, infrequent in the staging post area.

Lauraceae

Cassytha filiformis L.

Gan islet, eastern tip, *Sigee 28*. Common in open grassland near buildings, and found in all open habitats over the island. Hitaddu islet, very common in the scrub of the staging post area, and frequent in the open woodland on the lagoon sides of the southern and northern forest.

Hernandiaceae

Hernandia sonora L.

Gan islet, near oil tanks, on bank, 10 yards from sea, *Sigee 14*. Single tree on the lagoon shoreline, and a few trees inland in the scrub area south of the central woodland. Hitaddu islet, seen as an infrequent tree or bush on the lagoon side of the northern forest.

Capparidaceae

Cleome viscosa L.

Gan islet, on roadside, *Sigee 34* (glabrous form), *Sigee 34b*. Common in dry, open habitats such as roadsides and open grassland. Hitaddu islet, common in dry areas of the staging post scrubland, particularly on the seaward side. Specimens on Hitaddu were more pubescent than those on Gan.

Crassulaceae

**Kalanchoe pinnata* (Lam.) Pers.

Bushy islet, in clearing on rough ground, *Sigee 70*. Common in the clearings in the wooded area. Hitaddu islet, seen only in the banana plantation north of the staging post.

Moringaceae

**Moringa oleifera* Lam.

Gan islet, *Sigee 107*. A single tree in the graveyard of the Mosque, adjacent to the Pakistani village.

Leguminosae

Canavalia cathartica Thou.

Gan islet, lagoon shore, climbing on *Scaevola* in shade of palm tree, *Sigee 6*. Common on lagoon and southeast coastal scrub. New record for the Maldives, first found there by Groves in 1943-45.

**Cassia occidentalis* L.

Gan islet, south end of island, east side, in open wasteland, *Sigee 48*. Uncommon, individual plants were scattered over open grassland and by roadsides. Hitaddu islet, uncommon, seen only in dry parts of the staging post scrub.

**Clitoria ternatea* L.

Gan islet, in gardens, *Sigee T*.

Crotalaria retusa L.

Gan islet, eastern tip, in scrub, near sea, *Sigee 29*. Fairly common along roadsides and in scrub at the southeast end of the island.

**Delonix regia* (Boj.) Raf.

Gan islet, *Sigee 32*. A few trees lined the roadway along the northern perimeter.

**Dolichos lablab* L. ?

Hitaddu islet, in *Scaevola-Tournefortia* hedge, lagoon side, *Sigee 92*. A few plants seen along the lagoon shore at the northern end of the staging post area.

Erythrina variegata L.
(*E. indica* L.)

Gan islet, Pakistani Camp, near graveyard, near wall of buildings, *Sigee 108*. A single large sterile tree occurred on the southern side of the Mosque, near the Pakistani village.

Sesbania bispinosa (Jacq.) F. W. Wight

Gan islet, golf links, grass stand, *Sigee 65*. Uncommon, seen in open grassland and by roadsides. New record for the Maldives.

Vigna marina (Burm.) Merr.

Gan islet, west of promontory, east end, lagoon; coloniser, on sand banks near sea, *Sigee 21*. Common along lagoon shoreline.

Surianaceae

Suriana maritima L.

Gan islet, at edge of *Scaevola* bush, south side of island, *Sigee 49*. Single plant found near the seaward coast. Hitaddu islet, common along parts of the seaward shore, a few specimens found on the lagoon shoreline.

Euphorbiaceae

Acalypha indica L.

Hitaddu islet, in scrubland, centre of island, *Sigee 103*. Common in dry parts of staging post scrub. Gan islet, common in dry scrub and by waysides.

Acalypha lanceolata Willd.

Gan islet, waste ground, on coral pile, *Sigee 83*. An uncommon plant, found in open grassland, roadsides and scrub.

**Acalypha wilkesiana* M.-A.

Gan islet, in gardens, *Sigee Y*.

Agyneia bacciformis (L.) Juss.

Gan islet, in very wet area, *Sigee 112*. Common in the southeast open marsh area.

**Codiaeum variegatum* L.

Gan islet, *Sigee F*. Cultivated as an ornamental by the side of buildings.

Euphorbia cyathophora Murray
(*E. heterophylla* L. of ARB 58)

Gan islet, near oil tanks, at back of *Ipomoea* zone, *Sigee 11*. Common plant in scrub, and wasteland near buildings. Hitaddu islet, fairly common in banana plantation, also infrequent in staging post scrub.

Euphorbia hirta L.

Gan islet, wayside, *Sigee 88*. Common in scrub at southeast end of island, and along roadsides. Hitaddu islet, common in staging post scrub.

Euphorbia sp.

(Probably undescribed, of E. atoto-E. chamissonis group, but conspicuously pubescent; requires further study)

Gan islet, east end, lagoon side, in wasteland, bare open ground, Sigee 20.

*Manihot esculenta Crantz

Gan islet, Sigee N.

*Pedilanthus tithymaloides (L.) Poit.

Gan islet, in wayside, border, Sigee C. Common wayside ornamental. Recent introduction.

Phyllanthus madraspatensis L.

Gan islet, near oil tanks, on top of loose sand bank, 20 yards from tideline, Sigee 12. Common in all wasteland-scrub, roadsides and land near buildings. Hitaddu islet, common in staging post scrub.

*Phyllanthus urinaria L.

Gan islet, away from sea, near oil tanks, in wasteland, Sigee 23. Distribution as with P. madraspatensis: common in all wasteland-scrub, roadsides and land near buildings.

*Ricinus communis L.

Gan islet, rifle range, in open ground, near wayside, Sigee 44. Fairly common along roadsides and in dry areas of the scrub at the south-eastern end. Hitaddu islet, a few plants seen in the scrub around the staging post.

Malpighiaceae

Tristellateia australasiae Richard

Gan islet, in gardens, Sigee AC, U. New record for the Maldives.

Sapindaceae

Allophylus cobbe Bl.

Hitaddu islet, in woody clearing in woods, Sigee 95 (sterile). An infrequent plant, seen only in the lagoon northern forest area.

*Cardiospermum halicacabum L.

Gan islet, grass sward, Sigee 33. Common in scrub, and occasionally seen in open wasteland around buildings.

Dodonaea viscosa L.

Hitaddu islet, in wasteland, Sigee 99. Common in coastal scrub south of the staging post. Gan islet, a few bushes seen in the central scrub.

Tiliaceae

Corchorus aestuans L.

Gan islet, in grassland near buildings, Sigee 61. Common in open grassland and along roadsides. Hitaddu islet, common in staging post scrub.

**Muntingia calabura* L.

Gan islet, west marsh, in tree-scrub woodland, small thicket, *Sigee 43*. Uncommon, bordering the marsh at the southeast end. Hitaddu islet, common in parts of the staging post area, where it was restricted to the marsh near the northern border.

Malvaceae

Abutilon indicum (L.) Sweet

Gan islet, south side, east end, *Sigee 47*. Uncommon, found in central scrub.

**Hibiscus rosa-sinensis* L.

Gan islet, *Sigee M.* Solitary bush, at northwestern tip of island.

Hibiscus solandra L'Her.

Gan islet, grassland, *Sigee 72*. Uncommon, occurring along roadsides and in open grassland. Hitaddu islet, uncommon in staging post area.

Hibiscus tiliaceus L.

Gan islet, seashore, lagoon side, very near to tide-line; a dense tree with no associated herbs but often with *Scaevola*, *Sigee 5.* Abundant along the shoreline and in the regenerating woodland in the centre of the island; common also in the central dense woodland. Hitaddu islet, common tree, growing in the coastal scrub on the seaward side south of the staging post area, and in open woodland on the lagoon side north and south of this.

Sida humilis Willd. ?

Gan islet, on mown grassland, *Sigee 109*. Common in open grassland and along roadsides, very widespread. Hitaddu islet, common in staging post scrub.

Guttiferae

Calophyllum inophyllum L.

Gan islet, south side, scrub, *Sigee 56*. A few trees in the area of regenerating woodland.

Turneraceae

**Turnera ulmifolia* L.

Bushy islet, clearing on rough ground, *Sigee 68*. Common in clearings in the centre of the woody area. Hitaddu islet, seen only in the banana plantation.

Passifloraceae

**Passiflora foetida* var. *hispida* (DC.) Killip

Gan islet, grassy scrub, *Sigee 63*. Common along roadsides and in the scrub. Hitaddu islet, uncommon, in the staging post scrub. New record for the Maldives.

**Passiflora suberosa* L.

Gan islet, south side, scrub, *Sigee 55*. Not common, but seen in the scrub, along roadsides, and clearings in the regenerating forest. Hitaddu islet, common in open, dry areas of the staging post scrub. New record for the Maldives.

Caricaceae

**Carica papaya* L.

Gan islet, in open wasteland, *Sigee 50*. A few trees occurred in the southern coastal scrub, and around the buildings at the northern end.

Cucurbitaceae

**Cucumis melo* L.

Gan islet, on rough ground, concrete rubble, between oil tanks, *Sigee 15*. Common in the grass verge by roadsides, and in the scrub clearings. Hitaddu islet, common on bare ground in staging post area, seaward side. New record for the Maldives.

Lythraceae

Ammania baccifera L.

Gan islet, near coral heap, wet ground, *Sigee 86*. Uncommon in the scrub, and localized in a small marsh area. Hitaddu islet, uncommon in the staging post scrub, where it was localized in the marsh at the northern boundary. New record for the Maldives.

Pemphis acidula Forst.

Gan islet, lagoon shore, in open, about 2 yards from high tideline, among *Ipomoea*, *Sigee 7*. Uncommon; a few specimens seen in the seaward coastal scrub. Hitaddu islet, common as the shoreline shrub along parts of the seaward coast, and in the coastal scrub behind the shoreline. A few specimens were also seen on the lagoon side. Bushy islet, rock spits going out to sea on ocean shore, *Sigee 69*. A common shrub, occurring along the whole periphery of the island, and in places washed by the tide.

Rhizophoraceae

Bruguiera gymnorhiza Lam.

(*B. conjugata* (L.) Merr. of ARB 58)

Hitaddu islet, south end, lagoon side, *Sigee 110*. Single specimen seen on the lagoon shore, south of the staging post, in an area of local surface water.

Combretaceae

Terminalia catappa L.

Gan islet, *Sigee 71*. A few trees seen in the area of buildings at the northwest end. Hitaddu islet, uncommon, occurring in the northern forest near the seaward coast.

Myrtaceae

**Eugenia cumini* (L.) Druce
Gan islet, center, *Sigee 77*. The tallest tree on the island, dominating the central woodland; also occurring as juvenile specimens in the regenerating woodland nearby. New record for the Maldives.

Apocynaceae

**Catharanthus roseus* (L.) Don
Gan islet, in wayside border, *Sigee A.* Recent introduction, very common along the wayside border as an ornamental.

**Nerium indicum* Mill. ?
Gan islet, bush, wayside, *Sigee B*. Recent introduction, very common along wayside border.

Ochrosia oppositifolia (Lam.) K. Schum.
Gan islet, along eastern end, near road, solitary in scrub, *Sigee 45*. Uncommon, seen only in regenerating woodland.

**Plumeria obtusa* L.
Gan islet, *Sigee H*. Recent introduction, wayside shrub.

**Plumeria rubra* f. *acutifolia* (Poir.) Woods.
Gan islet, *Sigee G*.

Concolvulaceae

**Argyreia nervosa* (Burm. f.) Bojer
Gan islet, *Sigee E*. Single specimen seen, cultivated as a creeper on an erected cane framework. New record for the Maldives.

Ipomoea littoralis Bl.
Hitaddu islet, in clearing in woodland, *Sigee 115*(sterile). A single colony seen in the northern forest, near a disused native dwelling.

Ipomoea pes-caprae (L.) R. Br. ssp. *pes-caprae*
Gan islet, seashore, in dense mats about 20 yards from sea, *Sigee 1*. Abundant on the lagoon shoreline, and behind the coastal shrub on the seaward side. Hitaddu islet, abundant on the lagoon shoreline, occurring also in parts of the open woodland on the lagoon side. A few plants seen in clearings in the seaward coastal scrub.

Ipomoea tuba (Schlecht.) G. Don
Gan islet, south of runway, east end, almost marsh (high water table), *Sigee 37*. Common in southeast open marsh area, and also in scrubland at that end of the island. Hitaddu islet, uncommon, in northern forest.

Jacquemontia paniculata (Burm.f.) Hall. f.
Gan islet, south side, scrub, grass, with *Ipomoea* vines, *Sigee 54*. Generally uncommon, seen in open grassland, roadsides, and scrubland near the regenerating woodland. Hitaddu islet, common in the scrub of the staging post, where it covered local areas of otherwise bare ground.

Boraginaceae

*Cordia curassavica (Jacq.) R. & S.
Gan islet, in gardens, Sigee 23a, Z. New record for the Maldives.

Cordia subcordata Lam.
Gan islet, end of island, Sigee 79. Uncommon, occurring near buildings.

Tournefortia argentea L.f.
(Messerschmidia argentea (L.f.) Johnst.)
Gan islet, seashore, lagoon, 5 yds from tide-line; open habitat, Sigee 8. Common along shoreline, and in coastal scrub at southeast end of island. Scattered as an infrequent shrub in the scrub farther inland, and a few colonising bushes seen in the open marsh area. Hitaddu islet, common along parts of seaward coast as shoreline shrub, and also in the coastal scrub behind the shoreline. Common also in the staging post area on the seaward side. Not common on the lagoon coast.

Solanaceae

Physalis angulata L.
(This specimen would correspond to P. minima L., which is probably just a reduced form of P. angulata L.)
Gan islet, near airstrip, grassland on disturbed area, Sigee 67. Common herb by the side of roads, occurring also in dry areas of the open grassland, and scrub. Hitaddu islet, fairly frequent in the dry areas of the staging post scrub.

Verbenaceae

*Lantana camara L.
Gan islet, Sigee S. Recent instroduction. A few bushes seen planted as wayside ornamentals at the northern end. New record for the Maldives.

*Lippia nodiflora L.
Gan islet, almost marsh (high water table area), Sigee 36. Seen only in the open marsh area at the southeast end, where it was common. Hitaddu islet, restricted to the marsh area at the northern boundary of the staging post, where it was locally common.

Stachytarpheta indica Vahl
Hitaddu islet, south end, on wasteland and in open forest, Sigee 100. Locally common in open grassland at the southern boundary of the staging post. New record for the Maldives.

Labiateae

Ocimum sanctum L.
Gan islet, near coral heap, dry waste ground, Sigee 87. Uncommon in central scrub. Hitaddu islet, uncommon in staging post scrub.

Stachys sericea Wall. ex Benth.
Hitaddu islet, north, in clearings, Sigee 116. Common in central staging post scrub, also found on the lagoon side of the northern forest. New record for the Maldives.

Scrophulariaceae

**Angelonia salicariaefolia* H. & B.

Gan islet, in gardens, *Sigee AB*. New record for the Maldives.

Bacopa monnieri (L.) Wettst.

Gan islet, in water in marshland, *Sigee 111*. Restricted to the southeast marsh, where very common.

Striga asiatica (L.) O. Ktze.

Hitaddu islet, north part, in forest clearings at lagoon side, *Sigee 94*. Localized in a small area on the lagoon side of the northern forest, near the northern boundary of the staging post. New record for the Maldives.

Bignoniaceae

**Spathodea campanulata* Beauv.

Gan islet, in gardens, *Sigee AA*. New record for the Maldives.

**Tecoma stans* L.

Gan islet, in gardens, *Sigee V*.

Acanthaceae

**Pseuderanthemum carruthersii* var. *atropurpureum* (Bull) Fosb.

Gan islet, *Sigee R*. Recent introduction. Planted as wayside bush.

**Pseuderanthemum carruthersii* (Seem.) Guill. var. *carruthersii* ?

Gan islet, in wayside, *Sigee D*. Recent introduction. Occurring in garden and as wayside bush near buildings.

Rubiaceae

Guettarda speciosa L.

Gan islet, lagoon side, on shore, *Sigee 10*. Common in the coastal scrub, and occurring frequently in the open scrub, and regenerating woodland. Hitaddu islet, common in the coastal scrub on the seaward side, and in the open forest on the lagoon side north of the staging post. Fairly frequent in banana plantation.

Hedyotis brachiata Wight

Gan islet, near coral heap, waste ground, *Sigee 85*. Restricted to a small area of open scrub at the southeastern end of the island. New record for the Maldives.

Hedyotis corymbosa (L.) Lam.

Gan islet, southern end, along wayside in rocky dust, *Sigee 51*. Commonly found by waysides, also seen in the scrub. Hitaddu islet, common in the staging post area.

Ixora coccinea L.

Gan islet, southern part of island, in bush scrub, *Sigee 52*. Locally common shrub, seen only in the regenerating woodland south of the central dense woodland.

Morinda citrifolia L.

Gan islet, *Sigee 58*. Hitaddu islet, common in the coastal scrub on the seaward side, and occurring also as a frequent shrub in the open woodland on the lagoon side of the northern forest.

Goodeniaceae

Scaevola taccada (Gaertn.) Roxb.
(*S. sericea* Vahl)

Gan islet, *Sigee 9*. Common along the shore as a shoreline shrub, and also in the coastal scrub. Frequent in the open scrubland in the regenerating woodland. A few bushes occurred as primary colonisers in the southeast marsh area. Hitaddu islet, abundant on the seaward coast both as a shoreline shrub, and in the dense coastal scrub behind the shoreline. Also common in the staging post scrub, and on the lagoon shoreline. A frequent bush in the open forest, north and south of the staging post; was a coloniser in clearings in the dense *Pandanus* forest on the seaward side north of the staging post area.

Compositae

**Bidens pilosa* L.

Hitaddu islet, in clearings in woodland, lagoon side, *Sigee 98*. Common on the lagoon side of the northern forest. New record for the Maldives.

Blumea sinuata (Lour.) Merr.

Hitaddu islet, in scrubland in open swampy area, *Sigee 104*. Uncommon, a few specimens found in the marsh area at the northern boundary of the staging post. New record for the Maldives.

**Conyza floribunda* Kunth

[This species seems to me insufficiently distinct from *C. bonariensis* (L.) Cronq. FRF.]

Gan islet, east end of island, just south of airstrip, in open scrub, *Sigee 30*. Seen only as a few clumps near the coastal scrub at the eastern end of the runway. New record for the Maldives.

**Eclipta alba* (L.) Hassk.

Gan islet, almost marsh (high water table), *Sigee 35*. Common in the southern marsh area, uncommon along roadsides and in scrub.

Launaea pinnatifida Cass.

Gan islet, seashore, *Sigee 3*. Common as a shoreline plant on lagoon side, also fairly frequent inland on bare ground. Hitaddu islet, common along the lagoon shoreline, spreading across bare sand.

**Tridax procumbens* L.

Gan islet, east end, just south of airstrip, on bare ground, open, *Sigee 31*. Common in parts of the open "grassland", roadsides, scrub and on the shoreline. Hitaddu islet, abundant in parts of the staging post area, near buildings, where it formed a compact turf.

Vernonia cinerea var. parviflora (Bl.) DC
(V. cinerea (L.) Less. of ARB 58)
Gan islet, away from sea, near oil tanks, in wasteland, more or less shady, Sigee 22. Common by roadsides, in scrub, and near buildings. Hitaddu islet, common in scrub of staging post area.

Wedelia biflora (L.) DC.
Gan islet, seashore, not normally washed by tide, Sigee 2. Abundant in open coastal vegetation, occurring just inland from shoreline. Also common in dry inland scrub. Hitaddu islet, abundant herb, forming complete ground layer in places, in the lagoon side open forest, north and south of the staging post. Also common in clearings in coastal scrub on seaward side, and common in open scrub of staging post area itself.

Name changes required in the Systematic list of plants of the Maldive Islands (ARB 58: 8-36, 1957)

Apluda varia var. aristata L. = Apluda mutica L.

Bambusa arundinacea Willd. = Bambusa spinosa Roxb.

Bambusa vulgaris Schrad. = Bambusa arundinacea Willd.

Eragrostis amabilis (L.) W. & A. = Eragrostis tenella (L.) Beauv.

Paspalum vaginatum Sw. = Paspalum distichum L.

Cladium jamaicense Crantz = Cladium jamaicense var. chinense (Nees)Koyama

Areca cathecu L. = Areca catechu L.

Rhoeo discolor Hance = Rhoeo spathacea (Sw.) Stearn

Cordyline terminalis (L.) Kunth = Cordyline fruticosa (L.) Goepp.

Ficus retusa L. = Ficus microcarpa L. f.

Gynandropsis gynandra (L.) Briq. = Cleome gynandra L.

Albizzia lebbek L. = Albizia lebbeck (L.) Benth.

Erythrina indica L. = Erythrina variegata L.

Triphasia trifoliata DC. = Triphasia trifolia (Burm. f.) P. Wils.

Euphorbia heterophylla L. = Euphorbia cyathophora Murr.

Phyllanthus nivosus Bull = Breynia nivosa (Bull) Small

Abroma augusta L. = Ambroma augusta L. f.

Eugenia jambolana Lam. = Eugenia cumini (L.) Druce

Ipomoea turpethum (L.) R. Br. = Operculina turpethum (L.) Manso

Messerschmidia argentea (L. f.) Johnst. = Tournefortia argentea L. f.

Physalis minima L. = Physalis angulata L.

Borreria ocymoides (Burm. f.) DC. = Spermacoce ocymoides Burm. f.

Scaevola sericea Vahl = Scaevola taccada (Gaertn.) Roxb.

Adenostemma viscosum Forst. = Adenostemma lavenia (L.) O. Ktze.

D. Marine benthic algae from Addu Atoll, Maldive Islands[1]

by Roy T. Tsuda[2] and Jan Newhouse[2]

The following is an annotated list of the marine benthic algae that were sent to the senior author by Mr. David C. Sigee. One terrestrial and one freshwater alga are also included in this paper. All collections were made in the proximity of three islands--Gan, Hitaddu, and Fedu on Addu Atoll, July to September, 1964.

Past published listings of the algae from the Maldive Islands are based solely on the collections from two expeditions--the J. S. Gardiner Expedition, 1892-1900, and the J. Murray Expedition, 1933-34. Barton (1903) describes 6 species, including 4 forms, 3 of the species from Addu Atoll; while Foslie (1903) enumerates 9 species of melobesioid algae, containing various forms, 2 of the species from Addu Atoll. Newton (1953) records one alga, _Microdictyon_ _pseudohapteron_ f. _luciparense_ Setchell, collected by the J. Murray Expedition from Mulakadu Atoll. To the authors' knowledge, only these three papers treat the marine benthic algae from the Maldive Islands.

HABITAT DATA

The following is a list of habitats on Addu from which the collections of algae were made or observed by Mr. Sigee.

A. _Gan Island_ - lagoon reef flat, shoreline to 100 feet.
B. _Gan Island_ - lagoon reef flat, 100 feet to 250 feet.
C. _Gan Island_ - lagoon reef flat, 250 feet to reef edge (360 feet).
D. _Gan Island_ - lagoon reef slope, to depth of 90 feet.
E. _Gan Island_ - seaward reef flat, shoreline to boulder zone.
F. _Gan Island_ - seaward reef flat, boulder zone to reef edge.
G. _Hitaddu Island_ - seaward reef flat, shoreline to 20 feet.
H. _Hitaddu Island_ - seaward reef flat, 20 feet to reef edge.
I. _Gan-Fedu Gap_.
J. On knoll in lagoon, 30 feet below the surface.

MARINE ALGAE

In the list of species below, the letters representing the habitats above refer both to the site where the species were actually collected and where the species were only observed. Where more than one habitat is listed for a species, there is no available information indicating which was the actual site of collection. It must be assumed that the collector was sufficiently competent to judge critical differences between the specific entities represented. All specimen numbers cited here are those of the collector, and the specimens are deposited in the herbarium of Dr. Maxwell S. Doty, University of Hawaii.

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Those five species which are recorded from Addu Atoll in both Barton (1903) and Foslie (1903) are incorporated in this listing and preceded by an asterisk.

Myxophyceae

Anacystis montana (Lightf.) Drouet & Daily
Habitat: E, *Sigee 120*.

Calothrix pilosa Bornet & Flahault
Habitat: E, *Sigee 120*.

Hormothamnion enteromorphoides Bornet & Flahault
Habitat: A, E, *Sigee 86*.
This species determination was made by Dr. Francis Drouet.

Lyngbya aestuarii Gomont
Habitat: B, C, E, *Sigee 26*, *79*, *87*.

Lyngbya majuscula Gomont
Habitat: A-F, *Sigee 16*.

Schizothrix calcicola (Ag.) Gomont
Habitat: E, *Sigee 88*.

Symploca hydnoides Gomont
Habitat: A-F, *Sigee 42*, *46*, *61*, *71*, *79*, *84*, *85*.

Chlorophyceae

Boergesenia forbesii (Harvey) Feldmann, 1938: 588, figs. 3-5.
Habitat: A, B, E, F, *Sigee 6*.
The elongated vesicles are in groups of 10-20. The bases of the vesicles in this collection are tapered with attached septate rhizoids.

Boodlea composita (Harv.) Brand, 1905: 187; Egerod, 1952: 362, figs. 6a, pl. 32a.
Habitat: B, E, F, H, *Sigee 94*.
Both specimens seem to fall within the limits of this species. No. 7 is much coarser with the main axis about 300 μ in diameter, while the main axis of No. 94 is about half that diameter.

Boodlea sp.
Habitat: D, *Sigee 63*.
The collection is a fine spongiose mass about a centimeter in diameter, with the presumed older portions of filaments approximately 25 μ in diameter and the younger portions as fine as 7 μ.

Bryopsis pennata Lamx., 1809: 134, fig. 1a-b, pl. 3; Egerod,1952:370,fig.7.
Habitat: A-F, *Sigee 14*, *54*, on coral.

Caulerpa lentillifera J. Ag., 1837: 173; Eubank, 1946: 418, fig. 2L;
Taylor, 1950: 67.
Habitat: A-D, *Sigee 8b*.

This specimen, which is 5 mm high from the prostrate axis, does not fall within the size range as described by Eubank (1946) or Taylor (1950), but is placed here because of its distinct constrictions at the points of attachment of the pedicels to the terminal heads.

Caulerpa racemosa var. *macrophysa* (Kütz.) Taylor, 1928: 101, pl. 12 (fig.3) and pl. 13 (fig. 9).
Habitat: A-D, *Sigee 8a*.

Caulerpa racemosa var. *peltata* (Lamx.) Eubank, 1946: 421, figs. 2r-s.
Habitat: A-C, F, H, *Sigee 9*, *13*.

Distinct peltate ramuli are present on both specimens.

Caulerpa serrulata var. *typica* (Weber-van Bosse) Tseng, 1936: 178, pl. 1.
Habitat: I, *Sigee 47*.

Caulerpa taxifolia (Vahl) Ag., 1822: 435; Eubank, 1946: 417, fig. 2f-g.
Habitat: A-C, *Sigee 10*.

Chaetomorpha brachygona Harvey, 1858: 87; Taylor, 1960: 70, pl. 2(fig.9).
Habitat: A, *Sigee 66*.

The filaments are about 150 μ in diameter and slightly constricted at their septa. The cells are less than two times as long as their diameter.

Chaetomorpha crassa (Ag.) Kütz., 1845: 204; Taylor, 1960: 72.
Habitat: A, *Sigee 106*.

The filaments, including the cell wall, are about 420 μ in diameter with the cell length less than twice their diameter. The thick cell wall is approximately 75 μ in diameter.

Chaetomorpha gracilis Kütz., 1845: 203; Taylor, 1960: 70.
Habitat: G, *Sigee 105*.

These filaments are about 45 μ in diameter with the length of the cells about two to four times as long as their diameter.

Cladophora sp.
Habitat: B-E, *Sigee 38*, *55*.

These intertangled filaments are light brown in color with their cells about 120 u in diameter. The length of each cell is about seven to eight times their diameter. The lateral branches usually occur on one side of the main filament.

Cladophora sp.
Habitat: A-B, *Sigee 73*.

Cladophoropsis sp.
Habitat: F, H, *Sigee 99*, *118*.

The lateral filaments are spaced irregularly along the main filament in a verticillate manner. The diameter of the main filament is about 550 μ.

Codium arabicum Kütz., 1856: 35, pl. 100 (fig. II).
Habitat: F, Sigee 123.

Codium edule Silva in Egerod, 1952: 392, fig. 18, pl. 35b.
Habitat: B, F, Sigee 22.

A branching repent specimen with the thalli not secondarily attached to each other. The size and shape of the utricles are very similar as those described in Egerod (1952).

Dictyosphaeria intermedia var. intermedia Weber-van Bosse, 1905; Taylor, 1950: 42.
Habitat: E, F, H, Sigee 40.

Two morphologically different thalli are included in this collection--a solid, pseudoparenchymatous cushion and a hollow monostromatic bladder. Both thalli lack trabeculae. The latter thallus also falls within the circumscription of D. cavernosa (Forsskål) Boerg. Egerod (1952) comments on these species saying that D. intermedia, in the later stages of development, is almost indistinguishable from D. cavernosa. Since these two thalli appear under the same collection number, it may be possible that these represent the young and old stage of D. intermedia. A more critical study of the haptera of both species is needed.

Enteromorpha sp.
Habitat: A, D, Sigee 68.

These thalli are about 7 cm high with branching occurring near the base. Both cylindrical and compressed branches arise from the base, with the former type about 150 μ in diameter and the latter type about 1 mm in diameter. The cells appear in longitudinal rows with two to four pyrenoids in each cell.

Halimeda discoidea Decaisne, 1842: 91; Hillis, 1959: 352, pl. 2 (fig. 5), pl. 5 (fig. 11), pl. 6 (fig. 11), pl. 7 (figs. 9-10), pl. 8 (figs. 5-8), pl. 11.
Habitat: A, B, F, H, Sigee 1.

The secondary utricles are very conspicuously inflated.

*Halimeda incrassata (Ellis) Lamx., 1812: 186; Hillis, 1959: 365, pl. 4 (figs. 1-2), pl. 5 (fig. 21), pl. 6 (figs. 21-24), pl. 12.
Habitat: below 25 fathoms and on hard bottom outside atoll, Barton, 1903; A, B, Sigee 75; A, B, F, Sigee 2b; F, Sigee 108.

The habitat data for these three specimens are listed here separately since the specimens appear morphologically dissimilar, but all three seem to fall within the circumscription of this species when examined anatomically. The surface utricles of specimen No. 2b are round in appearance and not angular as described by Hillis (1959). Aside from this, it seems to fall within this species.

*Halimeda opuntia (L.) Lamx., 1812: 186; Hillis, 1959: 359, pl. 2 (figs. 7-8), pl. 5 (figs. 3-4), pl. 6 (fig. 6), pl. 7 (fig. 3), pl. 10.
Habitat: below 25 fathoms and on hard bottom outside atoll, Barton, 1903; A, B, E, F, H, Sigee 2a, 3, 4.

These thalli are about 4-5 cm high with no specific holdfast present. The medullary filaments are fused in twos but occasionally may be seen in threes, with the points of fusion about 1-1.5 times as long as the diameter of the filaments. The primary utricles adhere to each other even after decalcification. These individual utricles are about 17 μ in surface diameter.

Neomeris mucosa Howe, 1909: 84, pl. 1 (fig. 5) and pl. 5 (figs. 1-14); Dawson, 1956: 42, fig. 30c.
Habitat: F, H, *Sigee 102*.

Of the seven species in this genus, these thalli agree with the description and figures of this species as described in Howe (1909).

Tydemania expeditionis Weber-van Bosse, 1901: 139; A. & E. S. Gepp, 1911: 66, fig. 153-154; Taylor, 1950: 73, pl. 38 (fig. 1).
Habitat: B-D, J, *Sigee 32*.

Only the distinct glomerular form of this species is present in this collection.

Udotea orientalis A. & E. S. Gepp, 1911: 119 and 142; Taylor, 1950: 74, pl. 38 (fig. 2).
Habitat: A-F, H, I, *Sigee 15*.

The thalli are small, about 3-4 cm high including the stipe, and anatomically similar to the description in Taylor (1950).

Valonia utricularis (Roth) C. Ag. 1822: 431; Taylor, 1950: 41.
Habitat: F, H, *Sigee 103*, *111*.

The vesicles are irregularly shaped with no organized pattern of branching.

Valonia ventricosa J. Ag., 1887: 96: Egerod, 1952: 347, pl. 29a.
Habitat: B-D, F, *Sigee 52*.

These vesicles are solitary, about one centimeter in diameter.

Phaeophyceae

**Dictyota bartayresiana* Lamx., 1809: 43.
Habitat: in passage below 25 fathoms and on hard bottom, Barton, 1903.

Dictyota friabilis Setchell, 1926: 91, pl. 13 (figs. 4-7) and pl. 20 (fig. 1).
Habitat: A-F, H, J, *Sigee 5a*, *70*.

Both collections form prostrate clumps, with the thalli about 1-2 cm long. Most of the thalli of No. 70 are less than 2 mm broad, whereas the thalli of No. 5a are about 5 mm broad. For the present, both of these sterile specimens are tentatively listed here.

Dictyota sp.
Habitat: A-F, H, J, *Sigee 5b*.

This collection consists of prostrate clumps with the thalli up to 3 cm long. The margins of the thalli are serrated as in *Dictyota patens* J. Ag., but do not conform to the growth habit and size of this species.

Hydroclathrus clathratus (Bory) Howe, 1920: 590; Taylor, 1950: 96.
Habitat: E, F, I, *Sigee 45*.

Padina commersonii Bory, 1828: 144; Okamura (Icones VI): 89, pl. 295.

Habitat: A, B, E, G, *Sigee 17*.

These thalli are about 5 cm high and arise from a common holdfast. The thalli are two to three cells thick, about 90 μ in thickness at the apical portion and enlarging to 120 μ in thickness below. The oogonia are in concentric rows on the upper surface above every hairline, with no inducium present.

Pocockiella variegata (Lamx.) Papenfuss, 1943: 469, figs. 1-14.

Habitat: B, D-F, H, *Sigee 50*.

The thalli were growing prostrate on fragments of coral. Although the anatomical sections as well as habit are similar to those described in Papenfuss (1943), there is still some doubt as to the legitimacy of the generic name.

Sphacelaria sp.

Habitat: A, B, *Sigee 28*.

These thalli are about 1-2 mm high. Since all of the thalli were without propagulae, no specific epithet can be designated here.

Turbinaria ornata (Turner) J. Ag., 1848: 266; Taylor, 1950: 101, pl. 53 (fig. 2) and pl. 55 (fig. 2)

Habitat: B, F, H, I, *Sigee 20*.

Rhodophyceae

The melobesioid corallines of the present collection are not reported here because of the authors' unfamiliarity with this group. However, two species described in Foslie (1903) are listed here.

Antithamnion sp.

Habitat: B, C, F, *Sigee 25*.

The branches on the main axis are either opposite or verticillate with the terminal branches tipped with a single acute shaped cell.

**Archaeolithothamnion schmidtii* Fosl.

Habitat: below 25 fathoms of water in lagoon, Foslie, 1903.

Botryocladia skottsbergii (Boerg.) Levring. 1941: 645; Dawson, 1956: 52, fig. 48.

Habitat: A-C, F, *Sigee 23*.

Ceramium fimbriatum Setchell & Gardner, 1924: 777, pl. 26 (figs. 43 & 44); Dawson, 1944: 317; Dawson, 1950: 123.

Habitat: G, *Sigee 105*.

The mature portions of the thalli are approximately 70 μ in diameter, with the corticating bands divided into two distinct parts at about the lower third. Short thick apically rounded, unicellular hairs are present at the nodes. The tetrasporangia are involucrate.

Ceratodictyon spongiosum Zanard., 1878: 36; Okamura, 1909 (Icones II): pls. 51-52.
Habitat: I, *Sigee 69*.
The thalli are very sponge-like in appearance.

Champia parvula (Ag.) Harvey, 1853: 76; Boerg., 1915-20 (Danish West Indies): 407.
Habitat: A, *Sigee 122a*.
The thalli are intertangled and form small clumps about 2 cm across.

Champia salicornoides Harvey, 1853; Taylor, 1960: 491, pl. 61 (fig. 5).
Habitat: A, *Sigee 122b*.
The thalli are about 3 cm high and appear erect from a basal disk. Anatomically, the walls of the thalli consist of a single layer of large cells, 25-50 μ in diameter, interspersed with smaller cells about 7-14 μ in diameter. The medullary filaments are seen running throughout the length of the thalli. The sessile pericarps are conical in shape and scattered on the thalli.

Dasya sp.
Habitat: H, *Sigee 112*.

Dictyurus purpurascens Bory *in* Belanger & Bory, 1846: 170, pl. 15 (fig. 2); Taylor, 1950: 143, pl. 78 (fig. 1).
Habitat: B, *Sigee 24*.
This collection is similar to the description and photograph in Taylor (1950).

Galaxaura marginata (Ellis & Solander) Lamx., 1816: 264; Kjellman, 1900: 77, Tab. 20 (fig. 44).
Habitat: B, C, *Sigee 104*.
The thalli are composed of flattened branches throughout. Terminal cells of the cortical filaments are spherical in shape.

Galaxaura rudis Kjellman, 1900: 43-44, Tab. 2 (figs. 1-9) and Tab. 20 (fig. 11).
Habitat: A, B, D, F, *Sigee 21*.
The thalli are 3-4 cm high and are bushy in appearance. Anatomically, the thalli consist of long assimilatory filaments with swollen cells at the basal portion of these filaments.

Gelidium divaricatum Martens, 1866: 30, pl. 8; Tseng, 1936: 36, figs. 18a-b, pl. 4.
Habitat: A-D, F, J, *Sigee 72*.

Griffithsia sp.
Habitat: C, *Sigee 80*.
The thalli are sterile and about a centimeter long.

Herposiphonia sp.
Habitat: B, D, H, *Sigee 78*.
These thalli were growing as epiphytes on *Halimeda opuntia*.

Hypnea spp.
Habitat: E, Sigee 91; E, F, H, Sigee 93; A, B, E, F, Sigee 18; B-D, Sigee 12.

Four species are represented in these collections of Hypnea. Due to the taxonomic difficulties encountered by the senior author in this genus, they cannot be named at present but are listed separately above with their respective habitats.

Jania capillacea Harvey, 1853: 84; Boerg., 1917: 198-199, fig. 188.
Habitat: A-F, H, Sigee 11.

The thalli appear as intertangled masses, with the branches seldom forming obtuse angles at the dichotomies. The diameter of the branches is approximately 120 u, with the length of the segments 6-8 times as long as the diameter.

*Lithothamnion fruticulosum (Kütz.) Fosl.
Habitat: below 40 fathoms, Foslie, 1903 (cited as an uncertain determination).

Lophosiphonia villum (J. Ag.) Setchell & Gardner, 1903: 329.
Habitat: B-D, F, H, J. Sigee 29, 98.

Polysiphonia ferulacea Suhringar in J. Ag., 1863 (Spec. Alg. II): 980.
Habitat: A-C, E, F, I, Sigee 35a.
Species determined by Dr. Hollenberg.

Spyridea filamentosa (Wulf.) Harvey in Hooker, 1833: 337; Taylor, 1950: 139; Dawson, 1954: 444, fig. 54i.
Habitat: E, Sigee 97.

The main axis is similar to the illustration in Dawson (1954). The determination branchlets are tipped with a single spine.

Tolypiocladia glomerulata (Ag.) Schmitz in Schmitz and Hauptfleisch, 1896-97: 441; Dawson, 1954: 452, figs. 59b-c.
Habitat: B, C, Sigee 44.

Vidalia serrata (Suhr.) J. Ag., 1863: 1125.
Habitat: B, Sigee 19.

The thalli are about 2 cm high with the stichidia present on the blades, just inside of the marginal serrations.

FRESHWATER AND TERRESTRIAL ALGAE

Nostoc commune Bornet & Flahault
Habitat: Terrestrial, Gan Island, Sigee 119

This blue-green alga was reported to be especially evident in wet weather.

Pithophora oedogonia (Mont.) Wittrock, 1877: 55, pl. 6 (figs. 1-6); Collins, 1909: 363.
Habitat: Freshwater, Gan Island, Sigee 114.

The filaments of this green alga are branched with cells about 60 u wide and the cell length about ten times as long as the diameter. Both intercalary and terminal akinetes are present.

Summary of Algal Collection

Excluding the four tentative species of Hypnea, this paper lists 63 species or varieties of marine benthic algae from Addu Atoll, 58 of them reported here for the first time from this atoll. These new records consist of 7 in the Myxophyceae, 25 in the Chlorophyceae, 7 in the Phaeophyceae, and 19 in the Rhodophyceae. One terrestrial alga and one freshwater alga are also included in this paper.

It is of great interest to note that the species represented here from Addu Atoll in the Indian Ocean are very similar to the marine flora that occurs on many of the atolls in the Pacific Ocean.

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VI. ADDU ATOLL IN 1836

The following text is taken from an unpublished manuscript by Commander R. Moresby, "Nautical directions for the Maldive Islands", written following the first hydrographic survey, and preserved as MS 55 in the India Office Records, Commonwealth Relations Office, London, by whose permission it is reproduced.[1/] Excerpts from Moresby's work have been previously published (Moresby 1835, 1844), and his officers also published early descriptions (Christopher 1841, 1844; Young and Christopher 1844), but Moresby's full memoir has not previously been published, though Darwin (1842) drew on it, and it is briefly mentioned by Gardiner. The original forms a volume of 98 manuscript pages, of which pages 39-46 deal with Addu Atoll.

Addoo Atoll

Addoo Atoll erroneously called by former Navigators Phoohah Moloque Atoll, this Atoll being rich, well inhabited, and available for Ships, much in want of supplies; I shall be particular in describing it. This Atoll terminates the South extreme of the Maldive chain of Islands, is the smallest of all the Atolls; being only 10 Miles from East to West. and 7 miles from North to South, it is of a half Moon Shape, the concave side facing the north, and the convex side the South. The NW Point is in Lat^{de} 0°35' South. Long^{de} 73°6½ East. The NE Point in La^{de} 0°35 South and Long^{de} 73°10½ E. there are nine larger and several smaller Islands; the two principal Islands lay, one on the NW point; the other on the NE^{n} point; that
on the NW^{n} part of the Atoll, is named Hit-ta-doo. and extends to the SSE
39 5 miles, its breadth from ¼ to ½ of a mile; next to the South of it is / is
40 Merra-doo. about one Mile in extent; then Faidoo which is smaller, next
to the south is Gung, which is 1½ Mile in extent, and is the most Southern and centre Island of the Group; all these Islands four in number, lay on the Western side of the Atoll, and are connected by a barrier reef. of coral, dry at low water, with no Soundings outside of them.

There are four Channels leading into this Atoll; two in the Centre, on the North side, and two in the centre on the South side; the Southern channels are the largest, and may be used at night time; the Northern ones are not so broad; yet are safe. and available for vessels coming from the North^{d} with northerly winds, or leaving the Atoll with Southerly winds. a vessel could not work through the Northern Channels, but with a fair tide it could be don through the Southern ones; the best way is to adopt
40 that channel through which a vessel will have a fair wind; the Northern
41 Channels are not easily seen by a vessel coming from the Northward./as
the Northern barrier at some distance appears like one unbroken Reef; on a nearer approach and almost in the centre of this barrier, between the East and Western Islands, lay the channels; which will be known by a small bushy Island and a high Bank of Coral Stones; both on the Same Reef; on

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[1/] Unpublished Crown-copyright material in the India Office Records transcribed in this chapter appears by permission of the Secretary of State for Commonwealth Relations.

either side of them is a channel leading into the Atoll, the eastern
Channel is the largest being 4 or 500 yards broad, having not less than
6 & 7 fms, its direction NW and SE^{n}; the Western Channel is narrower yet
longer, and its direction North and South, the depths are from 10 to 12
fms; in both these channels the tides and currents are strong. as also in
the Southern ones; the Flood tide sets into the Northern Channels; the
Ebb sets into the Southern ones, rise and fall of the tide about 4 feet,
high water at 1 hour full and change of the moon. The Southern Channels
41 lay on the East side of Gung Island the Southern Island of the / the Atoll;
42 this I shall call Gung Channel and is formed between Gung Island. and two
small Islands to the ENE of Gung, called Willing-gilly Islands. Gung
Channel is half a mile broad, having no dangers in it. and the depths are
from 13 to 17 fms. it is convenient for any Ship entering the Atoll. The
other Channel I shall call the Willing-gilly Channel is on the East side
of the Willing-gilly Islands, formed between them and the South Point of
the dry coral reef bounding the East Side of the Atoll; this channel is
one mile broad and has from 17 to 20 fms water in it; deepening as a Ship
enters the Atoll; the direction of this Channel is about NW & SE about
one mile inside the entrance, on the NE side, there is a small Coral reef,
and as a Vessel proceeds on to the centre of the Atoll, 3 coral patches
will be observed on which the sea breaks at times; but these are easily
avoided by a common look out; the deepths in the centre of the Atoll are
42 from 25 to 35 fms sand and clay; the most convenient anchorage for com-
43 munication with the Natives is near the Islands on the West side all / all
of which are inhabited; from the Willing-gilly channel round the NE^{n} Side
of the Atoll; to the Centre on the North side, is one continued barrier
reef, on which are several Islands, the only large one of two miles in
extent, is on the NE^{n} part of the Atoll this is well inhabited and an in-
teresting Island it is called Mee-doo and Hoo-loo-doo from two villages
situated in its Centre.

This Atoll is clear of Reefs except in the Centre, the three small
patches as formerly mentioned; and which are easily avoided; 30 & 35 fms
is the depth of water in the Centre. Near the Islands on the East and
West sides, are 20 & 25 fms. a vessel may Anchor as Most convenient, ac-
cording to the Seasons; during the NE^{n} Monsoon on the north or Weather
side, and in the other Monsoon on the West side. The Islands afford a
few Supplies, of Fruit - limes. Poultry Eggs. Water and Firewood in abun-
dance. the Natives are very civil and obliging, and will exchange their
43 articles either for Money or Rice, Biscuits, Sugar. Salt. Onions. Garlic.
44 they are extremely lazy / lazy and indolent and very timorous fearful of
strangers, and will not be induced to assist a Ship in Wooding, and Water-
ing, unless paid for it, and obliged to work; they are under the Govern-
ment of the Sultan at Male, or King's Island; and the Atoll-Warree or
Chief of the Atoll is the person Strangers ought to apply to, for assis-
tance in getting Supplies; Some of the Natives speak the Indostannee
language; their principal occupation is making cotton Cloths, of White,
Red, and Black colours mixed; all of which they dye themselves. and sell
at a good price in the other Atolls; they are not allowed by their Govern-
ment to trade with Foreigners, not even with the English their Allies;all
this produce must be sold at the King's Island Male. They seldom visit
Ships passing, from fear of molestation; and it would be wrong any Ships

stopping at these Islands; to allow their Crew to intrude into the
privacy of their houses, among their females, or wantonly and without
44 permission to take their fruit. coconuts. fowls &c. they are poor, and
inoffensive, and have reason / to regret the visits of some Merchant
45 Ships; in Religion they are all Musselmen. the Atoll contains about 500
inhabitants and in appearance they are like the Natives of India on the
Malabar coast.

There are no soundings outside of this Atoll close to the barrier reef. and being to the South^{d} of the line or Equator. is almost without the influence of the Monsoon: the Winds and Weather being very variable. subject to Squalls. and Rain. The NE^{n} Monsoon is felt in Jan^{ry} Feb^{y} & March. and Westerly winds more in July August & Sept^{r}. the currents about this Atoll are very Strong, for six months they set to the West^{d} and then back again to the East^{d} according to the Monsoons. but are subject to checks from variable winds. They commence to set to the West about January and to the East^{d} about June. their velocity from 40 to 50 Miles per day. decreasing considerably in strength 40 or 50 Miles from the Islands. there was in 1836 no variation of the Magnetic.

45 I have been thus particular as so many Ships pass this place on
46 their way to & from India. /

I have also recommended it as a Coal Depot for Steamers.

VII. BIBLIOGRAPHY OF THE MALDIVE ISLANDS

This bibliography covers the reefs, islands, zoology, botany, and peoples of the Maldive Islands. A basic source is the bibliography by Sachet and Fosberg (1955), together with the references listed by Haas (1961) and Eibl-Eibesfeldt (1964). Dr. Sachet verified or corrected some of the entries, and added a large number from her unpublished bibliographies. Her help is gratefully acknowledged. The bibliography also includes some items not specifically concerned with the Maldive Islands, but referred to in this report; these are noted with an asterisk.

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ATOLL RESEARCH BULLETIN

No. 117

Atoll News and Comments

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ATOLL NEWS AND COMMENT

Future of the Atoll Research Bulletin

For 15 years, with the support of the Geography Branch, Office of Naval Research, we have been able to distribute the Atoll Research Bulletin gratis to scientists and institutions interested in research on atolls and reefs, to agencies concerned with administration of coral islands, to schools on islands, and to a considerable number of libraries geographically situated so that the Bulletin would be reasonably accessible to most people who might be occasionally interested in consulting it. Unfortunately the ONR finds it no longer possible to continue this support, and we have not yet found another source of funds to carry it on. The National Academy of Sciences was approached with a proposal to continue publication of ARB on a subscription basis, but gave us no encouragement. Hence, this will be the last issue under the present auspices, and, unless we can find another sponsor and at least a certain amount of financial backing, it will be the last issue published. We are sorry, as the ARB seems to be useful and appreciated.

We are seeking other sponsorship and funds, and if successful, hope to resume publication in the not too distant future. However, there seems little hope that ARB could again be distributed gratis. We will have to aim to put it on an eventually self-supporting basis, which will mean subscriptions. If we succeed you will hear from us, and we will ask you to subscribe. Please wish us luck! Any expressions of interest or suggestions as to possible sources of support will be gratefully appreciated.

The editors have recently transferred their main activities from the U. S. Geological Survey to the Smithsonian Institution. However, all mail concerning the Atoll Research Bulletin and the Pacific Vegetation Project should continue to be addressed to them c/o National Academy of Science-National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418, USA.

Demise of Unesco Humid Tropics Research Programme

It is distressing to have to announce the demise of what seemed to be a very promising scientific effort, the Unesco Humid Tropics Research Programme. This program was somewhat patterned on the Unesco Arid Zone Programme, which was,in general, a very successful effort. The chief tangible accomplishments of the Humid Tropics Programme were a number of very interesting symposia, nine of which have been published; two more were not, though it is still planned to publish one of them if possible. The Programme was plagued by administrative difficulties and lack of adequate funds to do anything very impressive. The most effective single activity, perhaps, was the Visiting Committee for Tropical Herbaria, set up to help and advise the herbaria located in the tropics. The Manual for Tropical Herbaria (see ARB 112, p. 11) was prepared under its auspices. This committee is theoretically still in existence, but the money intended for its activities during the current biennium was spent for other things. We hope it will be picked up again in 1967. One cannot help having the feeling that a factor of critical importance in the failure of Unesco to continue support for the Humid Tropics Programme was the policy, adhered to by the International Advisory Committee on Humid Tropics Research, that the task of Unesco scientific programs should be fundamental or basic research, and that they should not encroach on the fields of the practical specialized agencies like FAO and WHO. The underdeveloped humid tropical countries, that should have rallied to the support of this program, were apparently not able to realize that the benefits of applied science mostly result from previous basic science.

Atolls for Science

A proposal, put forward by Gene Wallen, director of the Smithsonian's oceanography program, to acquire one or more atolls to be preserved as reserves for scientific study is under serious discussion. Coral atolls,as is of course obvious to ARB readers, are among the most remarkable natural phenomena. Most of them have already been seriously altered by man, but a few unspoiled ones remain, and others are not so far gone that they will not preserve or recover their essential character if they are protected from the more destructive sorts of human activities. It is hoped that the means may be found to set aside a small number of representative atolls, and that an effective way may be found to administer and protect them, both their land areas and their under-water features. This proposal is,as yet, in the dream stage, but worthwhile dreams may sometimes be the precursors of realities, and this one should certainly have the backing of all ARB readers.

Field Work

Caroline Atolls

Last summer, during July and August, F. R. Fosberg and Michael Evans were privileged to visit many of the atolls in the Yap District of the Trust Territory of the Pacific Islands, travelling on the last "field trip" of M.V.Roque. Ulithi, Lamotrek, Satawal, Woleai, Ifaluk, Eauripik, and Faraulap were visited, also the raised atoll, Fais. The visits were all too short for more than the hastiest work to be done, but extensive collections of vascular plants, with much ethnobotanical data, were gathered. Some of the specimens were, unfortunately damaged by mildew before they could be dried. The island of Satawal was the jewel of the lot. It has remained more isolated, because of difficult landing conditions, and as yet has no tin roofs and rather few of the other signs of western culture. The people are friendly, healthy, and alert, and have not yet forgotten their old ways in favor of foreign substitutes, as have so many others.

On Ulithi we visited Jim Boykin, principal of the high school on Falalop Islet, where students from all the atolls of the Yap District come for their secondary school training. The school occupies the abandoned U.S. Coast Guard Loran Station, and a substantial new building is under construction. Boykin is a biologist and is inculcating in his students an interest in and respect for their heritage of plants and animals. We certainly wish him every success in this effort.

Evans spent December in the Truk District, Central Carolines, and was able to visit Namonuito, Nomwin, Murilo, Nama, and Losap Atolls, and make collections of plants and ethnobotanical data.

This year's work, sponsored by the National Institute of Neurological Diseases and Blindness, NIH, has thus filled in some of the most conspicuous gaps in our knowledge of the floras of the Carolines. This leaves only a few of this group from which we have practically no knowledge. An expedition that was not dependent on Trust Territory "field trips", made for other purposes, but which had its own boat, could round out this floristic knowledge, with luck, in one season.

Carolines, Woleai Atoll

Dr. William H. Alkire, ethnologist currently of the Bishop Museum Expedition to the Carolines, spent the past year on Woleai Atoll, a real tropical paradise, and was due to leave in January. He is studying the relations of the Woleai people with their atoll environment, living as one of them, and gathering further data bearing on his theory of inter-island socioeconomic ties. The editor had the pleasure of an all too brief visit with him last summer. He has kindly sent us a collection of specimens of the plants of Woleai, with invaluable ethnobotanic information on them. He previously spent a year on Lamotrek Atoll, also in the west central Carolines (see below).

Original Observations

Chaschus Island, Persian Gulf*

The tiny island Chaschus lies about 20 kilometers northeast of Dharan, Saudi Arabia. It was visited briefly on November 15, 1957, by courtesy of the Arabian American Oil Company.

It is a cay of coral sand with a central pond and resembles a miniature coral atoll. It lies in a complex of coral reefs which are mostly submerged 1-3 meters.

The island is elongate in a north-south direction, parallel to the coast, and has low beach ridges along both sides, the east one slightly higher than the west. They enclose small sand flats and the small, elongate pond. This pond is mainly shallow but has a deep pool at the north end. At the south end is a shallow channel with a tiny stream of water running out, going sinuously southward and finally cutting through the east beach ridge and emptying into the Gulf.

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*/ These observations are scarcely sufficient to justify a separate number of ARB, but seem worth placing on record.

In the pond were a few individuals of a curious scypho-medusan, Cassiopeia andromeda. This animal rests on the bottom, its mass of short, thick slightly branched tentacles directed upward, gray brown and well camouflaged against the sandy bottom of the pond. It appears more like a sea anemone than a medusa, but is not attached. It moves very slowly over the bottom, and when turned over in the water it pulsates like a medusa, then turns over and sinks to the bottom.

The greater part of the land area is bare of vegetation, but the inner slopes of the beach ridges and the enclosed sand flats have an irregular sparse stand of yellowish fleshy low shrub, Suaeda aegyptia (Hasselq.) Zohary and a few mats of terete blue-green Arthrocnemum glaucum (Delile) Ungern-Sternb.

Along part of the east shore of the cay is a discontinuous exposure of thin beds of very soft, friable beach rock. At the south end this is dark gray-brown, the grains covered by a slimy dark organic matter. The remnants of the top layer are pale. It becomes harder toward the north, and the beds curve outward and fork, away from the present beach, into shallow water.

South of this, along the channel leading out of the pond, are two tiny strips of very soft beach rock, only about 2 centimeters thick, and dipping very slightly toward the channel.

The presence of this poorly consolidated beachrock suggests that the island has more stability than would be expected of what is essentially a loose, double sand-bar, thrown up by currents and wind. The fact that it appears on charts and has a name also suggests some sort of permanency. It also hints that perhaps severe storms that might completely sweep away such an island are not a common occurrence in the Persian Gulf.

F. R. Fosberg

Publications

Hogsty Reef, Bahamas

In the Christmas, 1965, number of Sea Frontiers (vol. 11, pp. 342-353) John D. Milliman and William M. Stephens present, under the title, "Rare Atlantic Atoll", a brief popular account of theories about atoll formation and a short but very interesting account of their visit to Hogsty Reef, a true atoll in the Bahamas, aboard the Research Vessel Gerda, last June. This is a tiny, but practically undisturbed atoll. Their description gives just enough information to make us hope they will write a more extensive account, and we will try to talk them into this if ARB solves its current problems and stays alive. We must especially congratulate Mr. Stephens on his marvellous photos that illustrate the article.

New Caledonia

We understand, although we have not yet seen a copy, that the first volume of Memoirs on New Caledonia reefs published by the Fondation Singer-Polignac (see ARB 112, p. 10) has recently issued.

British Honduras

A preliminary account of the results of the re-survey of hurricane effects on the British Honduras reefs and cays has been published by David Stoddart (Nature 207: 589-592, 1965)(see ARB 112, p. 4). This deals with changes in geomorphology and vegetation that have taken place since the survey made in 1962 (ARB 95), and resulting economic adjustments. Bird populations are said to have returned to normal. It is estimated that recovery in areas of major reef damage may take 25-30 years. Effects of differences in vegetation are indicated.

In another paper, "British Honduras cays and the low wooded island problem" (Inst. Brit. Geogr., Trans. and Pap. 36: 131-147, 1965), Stoddart has discussed the morphology of reef islets, using the British Honduras Cays as examples, in terms of their exposure to different wave-intensities and hence to different energy environments. He compares them with the similar cays on the Great Barrier Reef. The conclusion is that "As long as fundamental requirements of size, shape and depth are satisfied, the island type depends solely on available wave energy."

Beach rock

That the beach rock problems are not all solved, despite opinions expressed in some marine geological circles, is suggested by the appearance of a paper on Nature and origin of beach rock, by D. R. Stoddart and J. R. Cann (Jour. Sedim. Petrol. 35: 243-247, 1965), and of an Essai d'explication de l'origine des grès de plage. Cas des grès de plage coralliens, by J. Trichet (C. R. Acad. Sc. Paris 261: 3176-3178, 4469, 1965). R. F. McLean has also gone into some detail in an unpublished thesis on Mechanical and Biological erosion of beachrock in Barbados, West Indies, submitted to McGill University in 1964. Very probably pertinent to this subject, also, is a paper on Organic matter in recent and ancient limestones and its role in their diagenesis, by D. J. Shearman and P. A. d'E. Skipwith (Nature 208: 1310-1311, 1965), though in this paper there is no mention of the beach rock problem as such. The ideas expressed in these papers, and in the recent ones by R. J. Russell, are by no means all in complete agreement. In reading them one gets the feeling that either there are several distinct phenomena lumped together as beach rock because of similar end products of different processes, or that there is a principle involved in all that has not yet been isolated and understood and that the explanations so far advanced are all only partial, or even erroneous, solutions to the problem.

Pacific Bird Observer

We take this opportunity to welcome the newest addition to the list of serial publications carrying information on the natural history of the Pacific Islands, the Pacific Bird Observer. This is a bimonthly "Newsletter of the Pacific Ocean Biological Survey Program, Smithsonian Institution, Washington, D.C." (see ARB 112, p. 14). It is distributed to collaborators of the program "in order to promote the understanding of birds and their relation to man in the Pacific". The first three numbers have appeared and are attractively printed by offset, with drawings and excellent photos. There are many short articles of all sorts, mostly on aspects of the program, personalities, accounts of returns from banding, and in number 3, a description of Enderbury Island, Phoenix Is. We wish the newcomer a long and vigorous life.

Wake Island birds

We are happy to call attention to a very creditable short account of the birds of Wake Island, by Erin Casey (Elepaio 26: 63-64, 1966). 23 species of birds are listed, with some notes on their occurrence and abundance. It is of especial interest to note that the author is in the seventh grade at Punahou School, Honolulu. We hope that she continues and develops her interest in coral atolls and their birds.

Pendulum Gravity Measurements at Sea 1936-1959

This book by J. Lamar Worzel (John Wiley and Sons, 1965, $28.00) is essentially a compendium of basic data and as such is an important publication. It includes principal facts for the nearly 3000 pendulum gravity observations made by the Lamont Geological Observatory during the period between 1936 and 1959. All the information is provided about data reduction, base ties, etc. that anyone will need who wishes to make use of the data in the future. A good summary interpretation of the data is also provided along with a complete set of anomaly charts. The work reported here has made a major contribution to our understanding of the oceans and especially the zones of transition between continent and ocean.

The first chapter gives descriptions of the principal base stations, information on the methods of correction for temperature and air density, information on data reduction and a discussion of the accuracy of the observations. The second chapter consists of a brief description of each cruise including instrumentation changes, data reduction constants, the results of pendulum standardization at principal bases, and ties to secondary bases. The third chapter is a table giving the principal facts for all of the stations.

The fourth chapter is devoted to interpretation and gives a general discussion of the significance of the results and brief discussions of particular traverses, supplemented by cross sections. Much of this material has been published elsewhere, but it is valuable to have it collected in one place (especially the cross sections) with a summary of the conclusions. Most of this discussion is devoted to continental margins, oceanic trenches, and mid-oceanic ridges. Islands and sea mounts are allotted only three pages. The book will still be of interest to those concerned with coral reefs and islands, however, because of the general information it gives on the ocean basins as a whole and perhaps also because of the data given on the accompanying charts.

A series of appendixes gives track charts for the cruises, charts of the secondary base stations and summaries of the observations at such stations. There is also a list of references to other sources of sea pendulum data. Finally, two sets of charts are given, one for Bouguer anomalies and one for free air anomalies. All the available pendulum data from the literature is included along with the Lamont results. The charts show the anomaly values superimposed on bathymetric contours. The Bouguer charts also show generalized anomaly contours.

As pointed out by the authors, submarine pendulum gravity measurements will probably be supplanted in the future by surface-ship gravimeter measurements. The pendulum data will be useful, however, as a control network for the surface observations, and this volume provides the information necessary for that purpose.

William B. Joyner, Geophysicist
Regional Geophysics Branch
U. S. Geological Survey

Scientific and technical personnel in oceanography

ICO Pamphlet 21: 1-49, 1965, compiled by the Interagency Committee on Oceanography, of the Federal Council for Science and Technology, U.S.A.

This is a curious document. At first glance one would assume that it was a directory of people engaged in or concerned with oceanography. The foreword states that a survey of oceanographic personnel was undertaken and completed in 1964, reporting 2,649 individuals engaged in this work in the U.S. On page 6 is a definition of oceanography: "Oceanography is considered to be the scientific investigation of the world ocean, its living and non-living contents, boundaries, properties and processes." Following this, the 2,649 oceanographers are classified, described, discussed, and analyzed in about every way possible. But nowhere is there a list of who these people are or where they may be addressed. So the publication is, for most interested people, chiefly of academic importance.

Undersea vehicles for oceanography

ICO Pamphlet 18: 1-81, 1965, Interagency Committee on Oceanography of the Federal Council for Science and Technology, U.S.A.

This well illustrated and lucidly written paper may be of interest to students of the deeper water aspects of coral reefs. While SCUBA diving is clearly the most flexible method of studying these formerly inaccessible levels, more extended observations may be possible from some of the new submarines developed for undersea research. The current status of development of such craft is very well presented here. To childhood readers of Jules Verne, the absence of any mention of the Nautilus, prototype of these vehicles will be a wee bit disappointing.

Lamotrek, Caroline Islands

"Lamotrek Atoll and inter-island socioeconomic ties", by William H. Alkire (Illinois Studies in Anthropology 5: 1-180, 1965) has just come to our attention. This is a handsome little volume and, although primarily a work of social anthropology, is also an important contribution to atoll ecology and geography. In the anthropological field, in addition to placing on record a substantial amount of information on the day-by-day activities, environmental relations, and social structure of the Lamotrek, Elato, and Satawal societies, Alkire brings out, clarifies, and formulates a theory on the inter-island relationships in the atolls and islands in the Yap sphere of influence in the central Western Carolines. This is related to the size of the resource base and the vulnerability of the atolls to environmental vicissitudes, especially typhoons. This theoretical framework undoubtedly represents a major contribution to our understanding of the history and human geography of these islands, as well as to the strictly socioeconomic relationships.

Of perhaps greater interest to the readers of ARB is the information on Lamotrek and its satellite atolls contained in the chapter on the Setting, and that on Economic Activities. These atolls have been relatively little studied and this work will certainly be consulted as the basic source of information for some time to come. Since the author's main interests were in the social anthropological field, readers interested in ecology, geography, and even material culture are likely to be rather disappointed that data on the physical and biological environment and on actual products and methods used in material culture were not more systematically collected, or at least more adequately presented, if more information was gathered. Especially unfortunate is the author's dependence on previously published works, almost entirely applying to other atolls, for most of his basic environmental data. It would seem that, in 15 months spent on an atoll with less than half a square mile of land area, time might have been available to amass original information on the substratum, fauna and flora, rather than relying on accounts of other atolls and assuming that Lamotrek would be similar. There is, of course, considerable information from the author's own observations, but this must be carefully sorted out from the rest, in order to be sure that what is said actually applies to Lamotrek. The book is abundantly illustrated with photos, maps, and diagrams. An index would have been welcome, as would, even more, a vocabulary of the local terms used rather abundantly and explained only the first time (though the author says "The use of native terms in this work is kept to a minimum"). The lack of a list where such terms could be looked up readily seriously lessens the clarity and usability of the work as a whole.

In spite of these shortcomings, the appearance of a comprehensive work on Lamotrek is of great interest to all people interested in Micronesia and in atolls generally.

The Shape of Atolls

David Stoddart (Marine Geol. 3: 369-383, 1965) attempts to demonstrate, by statistical methods, some sort of consistency or homogeneity in the shape of atolls, an aim that would seem foredoomed to failure at first glance. He samples 99 out of 425 known atolls, and tries out a number of methods. We understand neither his basis for selection of the sample nor the significance of the methods chosen. Nor do we see how the study has "demonstrated the fundamental homogeneity of atoll shapes"; in fact, we cannot see that there is any such homogeneity. This is probably due to our lack of appreciation for the subtleties of the statistical approach, certainly not to any lack of diligence in applying it.

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